NAVIGATION

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Bioretention combined

Page Contents

Bioretention combined


Example of a rain garden planted with native vegetation.

Green Infrastructure: bioretention facilities are designed to mimic a site's natural hydrology

This document combines several documents related to bioretention. Individual documents can be viewed by clicking on the appropriate link below. Fact sheets are not included in this combined document. To view as a pdf, click on the link below. **NOTE the pdf is a static document and does not reflect changes made since the pdf was created on August 25, 2017.**

File:Bioretention combined.pdf

Links to individual bioretention articles

- Bioretention terminology (including types of bioretention)
- Overview for bioretention
- Design criteria for bioretention
- Construction specifications for bioretention
- Operation and maintenance of bioretention
- Assessing the performance of bioretention

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MPCA LINKS

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Stormwater

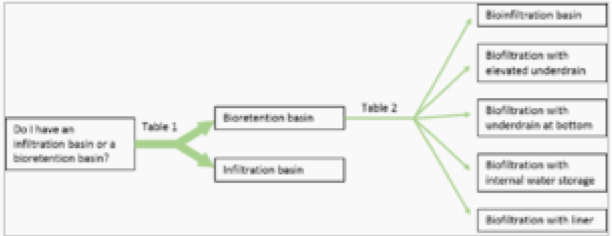
Policies / Disclaimers

- Cost-benefit considerations for bioretention
- Calculating credits for bioretention
- Green Infrastructure benefits of bioretention
- Soil amendments to enhance phosphorus sorption
- Summary of permit requirements for bioretention
- Bioretention photo gallery
- External resources for bioretention
- References for bioretention
- Requirements, recommendations and information for using bioretention with no underdrain BMPs in the MIDS calculator
- Requirements, recommendations and information for using bioretention with an underdrain BMPs in the MIDS calculator

Below are links to related articles that are not included on this page.

- Understanding and interpreting soils and soil boring reports for infiltration BMPs
- Determining soil infiltration rates

Terminology



Flow chart for determining the type of infiltration or bioretention device.

Infiltration basins and bioretention basins are terrestrial-based (up-land as opposed to wetland-based), water quality and water quantity control treatment practices with a required drawdown time of 48 hours or less. For basins within trout stream watersheds, the drawdown time is 24 hours or less due to the need to reduce discharge temperatures.

Although the difference between infiltration basins and the type of bioretention basin is not always clear, the figure to the right and tables below provide some clarity to differentiating between these stormwater control devices. Section drawings are included at the bottom of this page. Note the second table below provides a comparison of terminology used in this Manual with terminology used in the earlier versions of the Manual.

Summary of factors that can be used to determine differences between infiltration basins and bioretention basins. This table corresponds with Table 1 in the flowchart [1].
Link to this table

BMP	Typical position in watershed	Treatment scale	Typical storm sizes	Maximum drainage area guidelines	Maximum ponding depth guidelines	Growing medium
Infiltration (basin, trench, underground, dry well)	Downgradient of other water quantity or water quality control practices	Development or regional scale control	Less frequent large storm events that exceed capacity of upgradient practices	50 acres	4 feet	Native soil
Bioretention basin	Located throughout the watershed	Site scale control	Small storms (water quality events)	Typically 5 acres	Ideally 12 inches; can be up to 18 inches with appropriate design and plant selection	Engineered growing medium

Types of bioretention basins. This table corresponds with Table 2 in the flowchart [2].
Link to this table

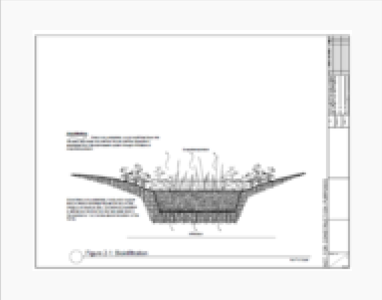
BMP	Typical uses; advantages	Relative amount of runoff abstracted from storm sewer system	2008 Manual terminology[1]
Bioinfiltration basin	Abstracts all runoff captured in the basin that does not leave through overflow	All runoff that flows into the basin and does not overflow into an overflow structure is abstracted from the stormsewer system through infiltration or evapotranspiration.	Infiltration / recharge facility
Biofiltration basin with underdrain at bottom	Allows for a small amount of infiltration, at a rate compatible with underlying soils, but carries away excess waterthrough the underdrain after it has been filtered through the basin	A small amount of the runoff that flows into the basin and does not overflow into an overflow structure is abstracted from the stormsewer system through infiltration or evapotranspiration; the remainder is filtered by the growing medium but then leaves via an underdrain.	Filtration / partial recharge

BMP	Typical uses; advantages	Relative amount of runoff abstracted from storm sewer system	2008 Manual terminology
Biofiltration basin with internal water storage (IWS)	Allows for more infiltration, at a rate compatible with underlying soils, but carries away excess water through the underdrain after it has been filtered through the basin; Internal Water Storage Zone (IWS) (1) allows for more infiltration and evaporation compared to bioretention with underdrain at the bottom; (2) improves thermal pollution abatement and nitrogen removal (longer retention time allows runoff to cool more before discharge and allows denitrification to occur under anoxic condition).	More of the runoff that flows into the basin and does not overflow into an overflow structure is abstracted from the stormsewer system through infiltration or evapotranspiration compared to bioretention with an underdrain at the bottom of the basin without an upturned elbow, because the upturned elbow increases hydraulic retention time; the remainder is filtered by the growing medium but then leaves via an underdrain with an upturned elbow.	Not included
Biofiltration basin with elevated underdrain	Allows for more infiltration, at a rate compatible with underlying soils, but carries away excess water through the underdrain after it has been filtered through the basin; elevating underdrain (1) allows for more infiltration and evaporation compared to bioretention with underdrain at the bottom (2) improves thermal pollution abatement and nitrogen removal (longer retention time allows runoff to cool more before discharge and allows denitrification to occur under anoxic condition).	More of the runoff that flows into the basin and does not overflow into an overflow structure is abstracted from the stormsewer system through infiltration or evapotranspiration compared to bioretention with an underdrain at the bottom of the basin, because the elevated underdrain increases hydraulic retention time; the remainder is filtered by the growing medium but then leaves via an elevated underdrain.	Infiltration / filtration / recharge

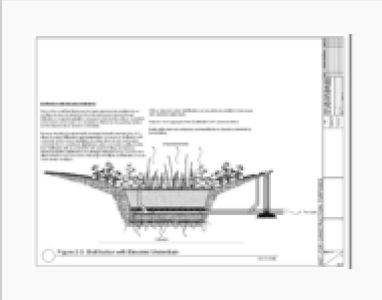
BMP	Typical uses; advantages	Relative amount of runoff abstracted from storm sewer system	2008 Manual terminology
Biofiltration basin with liner	Impervious liner reduces or eliminates possibility of groundwater contamination; underdrain can be blocked and objectionable materials siphoned through an observation well and safely contained; often used in areas of potential stormwater “hot-spots” (e.g., gas stations, transfer sites, transportation depots,industrial complexes etc.), or areas where groundwater recharge is undesirable	None of the runoff that flows into the basin is abstracted from the stormsewer system through infiltration but some is abstracted through evapotranspiration; i.e. all of the runoff that flows into the basin without flowing into an overflow structure, and is not evapotranspired, is filtered by the growing medium but then leaves via an underdrain.	Filtration only

[1]Terminology used in the 2008 Minnesota Stormwater Manual.

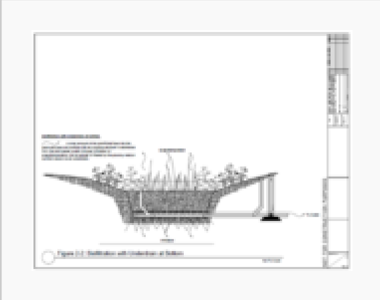
Section drawings for different bioretention devices. Click on an image for enlarged view. Also see Bioretention plan and section drawings.



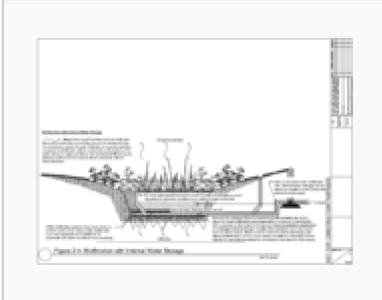
Bioinfiltration device



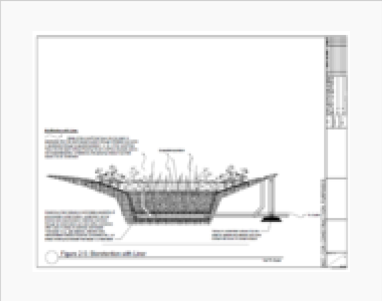
Biofiltration device with elevated underdrain



Biofiltration device with an underdrain at the bottom



Biofiltration device with internal water storage



Biofiltration device with a liner

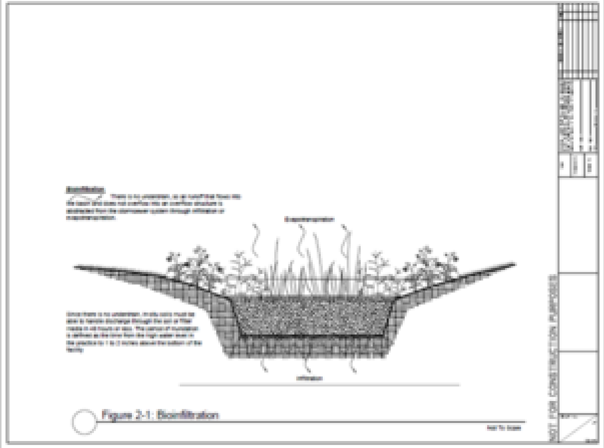
General discussion of types of bioretention BMPs

As bioretention becomes a more common tool in the stormwater management toolbox and as the number of design variants increases, so does the number of names for each of these variants. As an example of the ongoing evolution of bioretention terminology, the terms “rain garden” and “rainwater garden” have recently caught on with the public and are being used interchangeably with bioretention. In most instances, rain garden designs are utilizing the processes of bioretention, but the term rain garden is also being loosely used to describe BMPs that are operating more as stormwater ponds (or as other BMPs) than as bioretention facilities.

A bioretention facility (rain garden) in a residential area. Note the curb cut that allows water to enter the facility.

Bioinfiltration with no underdrain

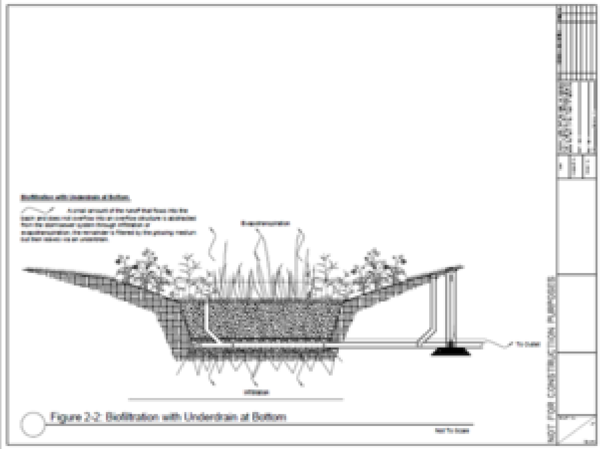
Bioinfiltration is suitable for areas where significant recharge of groundwater is possible and would be beneficial. Because there is no underdrain the in-situ soils need to have a high infiltration rate to accommodate the inflow levels. The infiltration rate of the in-situ soils must be determined through proper soil testing/diagnostics. The *Recommended* filter media depth is 2.5 feet or more to allow adequate filtration processes to occur. Most media mixes are suitable because phosphorus is not a significant concern with this practice. The CGP requires that water captured by the BMP be drawn down within 48 hours. A and B soils are commonly suitable for bioinfiltration. Bioinfiltration is suitable for areas and land uses that are expected to generate nutrient runoff (e.g. residential and business campuses) that can be infiltrated and captured by the practice. Fresh mulch rather then aged shredded bark mulch can be used to enhance denitrification processes if nitrate leaching is a concern. Bioinfiltration is not recommended for stormwater hotspots. Other infiltration constraints apply to bioinfiltration practices.



Bioinfiltration device

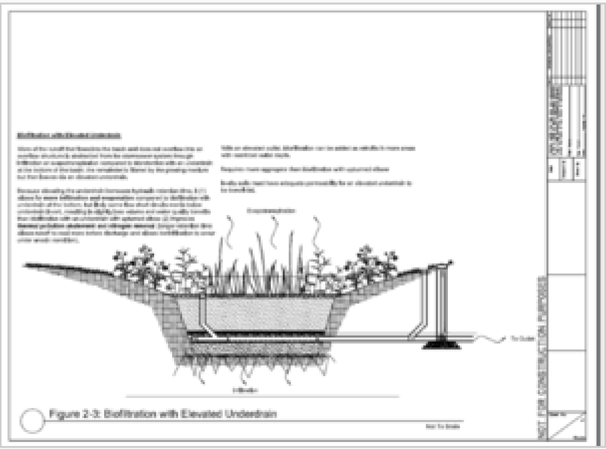
Biofiltration with underdrain at bottom

This bioretention practice is designed with an underdrain at the invert of the planting soil mix to ensure drainage at a desired rate. The practice allows for partial recharge and an impervious liner is not used. The depth is also shallow (2.5 feet) to allow high capacity flows if necessary. Siting is suitable for visually prominent or gateway locations in a community. The practice is suitable for areas and land uses that are expected to generate metals loadings (e.g. residential, business campus, or parking lots). The practice is suitable for areas with high nutrient loadings provided the media has a low phosphorus concentration or phosphorus-sorbing amendments are used (see section on filter media). This type of facility is also recommended for soils where infiltration is limited (C and D soils). Some volume reduction will be seen from evapotranspiration and partial infiltration below the underdrain.



Biofiltration device with an underdrain at the bottom

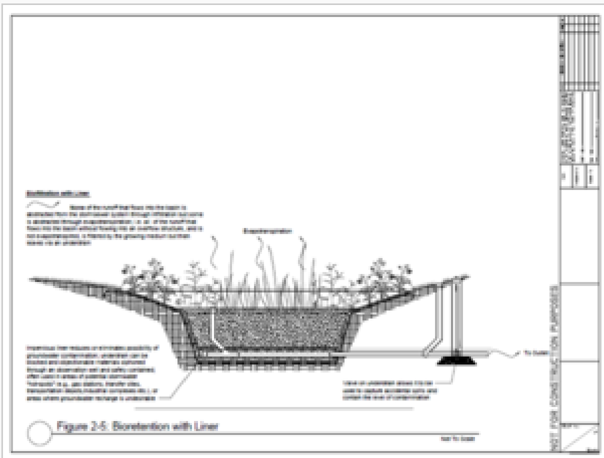
Biofiltration with elevated underdrain



Biofiltration device with elevated underdrain

A biofiltration practice with a raised underdrain provides a storage area below the invert of the underdrain discharge pipe. This area provides a recharge zone and quantity control can also be augmented with this storage area. The storage area is equal to the void space of the material used. Since the practice utilizes both infiltration and an underdrain, considerations include those for both bioinfiltration practices and biofiltration with an underdrain at the bottom. These include an assessment of infiltration constraints and media.

Biofiltration with a liner (at bottom and or on sides)



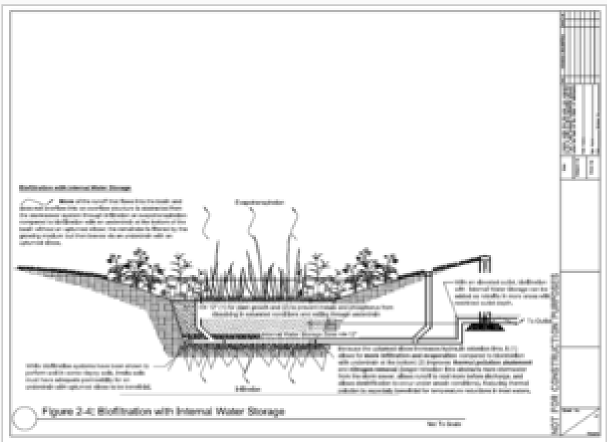
Biofiltration device with a liner

This type of facility is recommended for areas that are known as potential stormwater hot spots (e.g. gas stations, transfer sites, and transportation depots). An important feature of this type of facility is the impervious liner designed to reduce or eliminate the possibility of groundwater contamination. The facility provides a level of treatment strictly through filtration processes that occur when the runoff moves through the soil material to the underdrain discharge point. In the event of an accidental spill, the underdrain can be blocked and the objectionable materials siphoned through an observation well and safely contained.

Biofiltration with internal water storage

The biofiltration practice with internal water storage is not commonly used in the Midwestern United States but is widely used in some places on the east coast, such as North Carolina. The use of an upturned elbow in this practice allows water to be retained within the practice, leading to increased pollutant removal, increased infiltration, and increased evapotranspiration. The practice is particularly effective at removing nitrogen through denitrification. The media should be 3 feet or more thick to allow water to be

drawn down below the root zone. Underlying soils should be permeable enough to allow water stored within the practice to infiltrate. Hunt provides an overview of this practice.



Biofiltration device with internal water storage

Specific design applications for various land uses

It should be noted that the layout of the bioretention area will vary according to individual sites, and to specific site constraints such as underlying soils, existing vegetation, drainage, location of utilities, sight distances for traffic, and aesthetics. Designers are encouraged to be creative in determining how to integrate bioretention into their respective site designs. With this in mind, the following are presented as alternative options.

On-lot bioretention

Simple design that incorporates a planting bed in the low portion of the site. On-lot systems are designed to receive flows from gutters, and/or other impervious surfaces.

Parking lot islands (curbless)

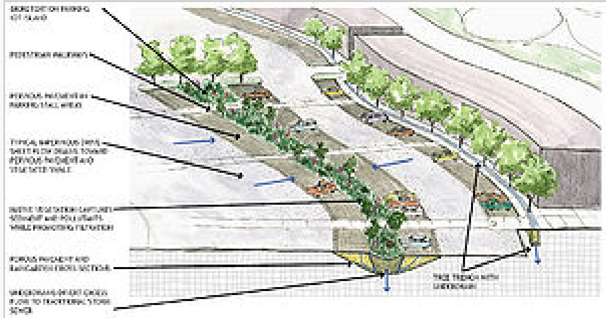
In a paved area with no curb, pre-cast car-stops or a “ribbon curb” can be installed along the pavement perimeter to protect the bioretention area. This application of bioretention should only be attempted where shallow grades allow for sheet flow conditions over level entrance areas. Water may be pooled into the parking area where parking spaces are rarely used to achieve an element of stormwater quantity control beyond the confines of the bioretention surface area (Prince George’s County, 2002).

Parking lot islands (curb-cut)

For curb-cut entrance approaches, the water is diverted into the bioretention area through the use of an inlet deflector block, which has ridges that channel the runoff into the bioretention area (Prince George’s County, 2002). Special attention to erosion control and pre-treatment should be given to the concentrated flow produced by curbcuts.

Road medians / traffic islands

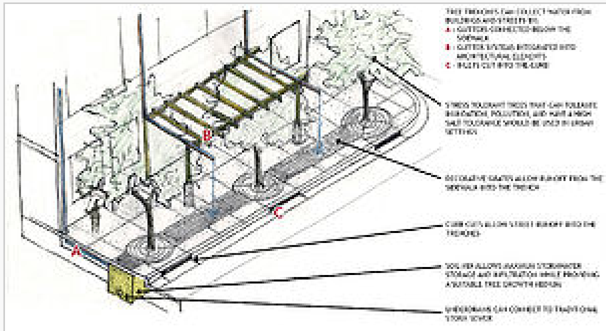
A multifunctional landscape can be created by utilizing road medians and islands for bioretention. There is no minimum width recommended for traffic islands from street edge to edge. A buffer may be necessary along the outside curb perimeter to minimize the possibility of drainage seeping under the pavement section, and creating “frost heave” during winter months. Alternately, the installation of a geotextile filter fabric “curtain wall” along the perimeter of the bioretention island will accomplish the same effect.



A bioretention parking lot island. Note the use of other BMPs, including permeable pavement and tree trenches. (Source: Minnehaha Creek Watershed District)

Tree pits / tree box filters

> **Information:** For a detailed discussion of bioretention practices that utilize trees, including design, construction, and O & M practices, see the section on trees.



A tree box filter. Note the curb cuts. (Source: Minnehaha Creek Watershed District)

Tree pits and tree box filters afford many opportunities for bioretention. Designs vary widely from simple “tree pits”, used for local drainage interception to more formal tree box filters, which are a useful tool for highly urbanized streetscapes.

The tree pit technique provides very shallow storage areas in a “dished” mulch area around the tree or shrub. Typically, the mulched area extends to the dripline for the tree and is similar to conventional mulching practices, except that the mulch area is depressed at least 2 to 3 inches rather than mounded around the tree (Low Impact Design Center, 2005).

Tree box filters are bioretention areas installed beneath trees that can be very effective at controlling runoff, especially when distributed throughout the site. Runoff is directed to the tree box, where it is cleaned by vegetation and soil before entering a catch basin. The runoff collected in the tree-boxes helps irrigate the trees. The system consists of a container filled with a soil mixture, a mulch layer, under-drain system and a shrub or tree. Stormwater runoff drains directly from impervious surfaces through a filter

media. Treated water flows out of the system through an underdrain connected to a storm drainpipe/inlet or into the surrounding soil. Tree box filters can also be used to control runoff volumes/flows by adding storage volume beneath the filter box with an outlet control device (Low Impact Design Center, 2005).

Overview

Bioretention is a terrestrial-based (up-land as opposed to wetland) water quality and water quantity control process. Bioretention employs a simplistic, site-integrated design that provides opportunity for runoff infiltration, filtration, storage, and water uptake by vegetation.


A rain garden in a residential development. Photo courtesy of Katherine McLellan.

Bioretention areas are suitable stormwater treatment practices for all land uses, as long as the contributing drainage area is appropriate for the size of the facility. Common bioretention opportunities include landscaping islands, cul-de-sacs, parking lot margins, commercial setbacks, open space, rooftop drainage and street-scapes (i.e., between the curb and sidewalk). Bioretention, when designed with an under-drain and liner, is also a good design option for treating stormwater hotspots (PSHs). Bioretention is extremely versatile because of its ability to be incorporated into landscaped areas. The versatility of the practice also allows for bioretention areas to be frequently employed as stormwater retrofits.

Function within stormwater treatment train

Unlike end-of-pipe BMPs, bioretention facilities are typically shallow depressions located in upland areas of a stormwater treatment train. The strategic, uniform distribution of bioretention facilities across a development site results in smaller, more manageable subwatersheds, and thus, will help in controlling runoff close to the source where it is generated (Prince George’s County Bioretention Manual, 2002). Bioretention facilities are designed to function by essentially mimicking certain physical, chemical, and

biological processes that occur in the natural environment. Depending upon the design of a facility, different processes can be maximized or minimized depending on the type of pollutant loading expected (Prince George's County, 2002).

Green Infrastructure: bioretention facilities are designed to mimic a site's natural hydrology

MPCA permit applicability

One of the goals of this Manual is to facilitate understanding of and compliance with the MPCA Construction General Permit (CGP), which includes design and performance standards for permanent stormwater management systems. Standards for various categories of stormwater management practices must be applied in all projects in which at least one acre of new impervious area is being created.

For regulatory purposes, bioinfiltration practices fall under Section 16 (Infiltration systems) described in the CGP. Biofiltration practices fall under Section 17 (Filtration systems) of the permit. If used in combination with other practices, credit for combined stormwater treatment can be given. Due to the statewide prevalence of the MPCA permit, design guidance in this section is presented with the assumption that the permit does apply. Also, although it is expected that in many cases the bioretention practice will be used in combination with other practices, standards are described for the case in which it is a stand-alone practice.

There are situations, particularly retrofit projects, in which a bioretention practice is constructed without being subject to the conditions of the MPCA permit. While compliance with the permit is not required in these cases, the standards it establishes can provide valuable design guidance to the user. It is also important to note that additional and potentially more stringent design requirements may apply for a particular bioretention practice, depending on where it is situated both jurisdictionally and within the surrounding landscape.

Retrofit suitability

The ability to use bioretention as a retrofit often depends on the age of development within a subwatershed. Subwatersheds that have been developed over the last few decades often present many bioretention opportunities because of open spaces created by modern setback, screening and landscaping requirements in local zoning and building codes. However, not every open area will be a good candidate for bioretention due to limitations associated with existing inverts of the storm drain system and the need to tie the

underdrain from the bioretention area (for practices requiring an underdrain) into the storm drain system. In general, 4 to 6 feet of elevation above this invert or use of an upturned elbow is needed to drive stormwater through the proposed bioretention area.

Special receiving waters suitability

The tables below provide guidance regarding the use of bioretention practices in areas upstream of special receiving waters. Note that the suitability of a bioretention practice depends on whether the practice has an underdrain (i.e. filtration vs. infiltration practice).

Summary of design restrictions for special waters.
Link to this table

BMP Group	receiving water				
	A Lakes	B Trout Waters	C Drinking Water	D Wetlands	E Impaired Waters
Filtration	Some variations NOT RECOMMENDED due to poor phosphorus removal, combined with other treatments	RECOMMENDED	RECOMMENDED	ACCEPTABLE	RECOMMENDED for non-nutrient impairments

Infiltration BMP design restrictions for special watersheds. This information applies to all infiltration practices.
Link to this table

BMP Group	Receiving water				
	A Lakes	B Trout Waters	C Drinking Water[1]	D Wetlands	E Impaired Waters
Infiltration	RECOMMENDED	RECOMMENDED	NOT RECOMMENDED if potential stormwater pollution sources evident	RECOMMENDED	RECOMMENDED unless target TMDL pollutant is a soluble nutrient or chloride

[1] Applies to groundwater drinking water source areas only; use the lakes category to define BMP design restrictions for surface water drinking supplies

It is *Highly Recommended* that bioretention practices be designed off-line. Off-line facilities are defined by the flow path through the facility. Any facility that utilizes the same entrance and exit flow path upon reaching pooling capacity is considered an off-line facility.

Cold climate suitability

Studies conducted since the 2008 version of this manual indicate the difference between summer and winter performance of bioretention systems is not substantial, even on sites with severe winters (Davidson, et al., 2008; Dietz and Clausen, 2006; Kahn et al., 2012; LeFevre et al., 2009; Roseen et al., 2009; Toronto and Region Conservation (TRCA), 2008). Davidson et al. (2008) provide several recommendations for bioretention systems in cold climates. These recommendations are consistent with design recommendations in the Minnesota Stormwater Manual.

Water quantity treatment

High-flow bypass systems are utilized to safely discharge stormwater when bioretention cells fill and reach their maximum ponding depth. This will occur during storms exceeding the water quality design storm. There are typically three types of high-flow bypass systems which are split into two categories: off-line and on-line. Whenever possible, off-line designs are preferable, as they reduce the potential for internal erosion in the bioretention cell. Off-line facilities are defined by the flow path through the bioretention cell. Any facility that utilizes the same entrance and exit point upon reaching maximum ponding depth is considered an off-line system. This is typically achieved with a curb cut set at the intended elevation of maximum ponding or through the use of some other upstream diversion, which results in flow bypass down the gutter when the cell has filled. This type of bypass is often simple to utilize in retrofit situations (commercial and transportation applications) where existing drainage infrastructure is present.

Where off-line designs are not achievable, it is *Highly Recommended* that bioretention practices be designed to route high flows on the shortest flow path across the cell to avoid scour in the bioretention practice. The overflow location should be placed as close as practicable to the inlet(s). No matter the bypass design, energy dissipation should always be provided at the inlet(s) to avoid high flow velocity and associated turbulence that can re-suspended particulates and cause erosion in the bioretention cell.

Two types of on-line bypass systems may be used. The first option is to utilize an internal drainage inlet. Concrete box drop structures may be used to provide an overflow for bioretention cells; however, they should be located away from the inlet(s) to provide an elongated flow path and prevent short-circuiting. These internal drainage structures may be tied into the existing drainage infrastructure, which is an attractive benefit in commercial applications. When using these high-flow bypass devices, it is critical to set the brink-of-overflow elevation properly, otherwise the cell will not function properly when construction is complete. In a tree-shrub-mulch cell, the internal drainage inlets should have a system of screens to prevent loss of mulch. These overflow devices should be designed to safely pass the design discharge.

A second option is to use a broad crested or compound weir in the berm of the bioretention cell to convey overflow. This will typically be the best option in residential, institutional, and rural bioretention applications, where the overflow can tie in to an existing surface conveyance (swale or ditch). Weir structures may be constructed of pressure-treated lumber, cast-in-place concrete, or precast concrete. The invert of the weir should be set at the intended brink-of-overflow elevation. This type of bypass structure should be designed to non-erosively bypass the design discharge.

In limited cases, a bioretention practice may be able to accommodate the channel protection volume, V_{cp}, in either an off-line or on-line configuration, and in general they do provide some (albeit limited) storage volume. Bioretention can help reduce detention requirements for a site by providing elongated flow paths, longer times of concentration, and volumetric losses from infiltration and evapotranspiration. Experience and modeling analysis have shown that bioretention can be used for stormwater management quantity control when facilities are distributed throughout a site to reduce runoff and maintain the pre-existing time of concentration. This effort can be incorporated into the site hydrologic analysis. Generally, however, it is *Highly Recommended* that in order to meet site water quantity or peak discharge criteria, another structural control (e.g. detention) be used in conjunction with a bioretention area.

No matter the type of overflow device used, it is important that the designer provide non-erosive flow velocities at the outlet point to reduce downstream erosion. During the 10-year or 25-year storm (depending on local drainage criteria), discharge velocity should be kept below 4 feet per second for grassed channels. Erosion control matting or rock should be specified if higher velocities are expected.

Water quality treatment

Bioretention can be designed as an effective infiltration / recharge practice, particularly when parent soils have high permeability (> ~ 0.5 inches per hour). Where soils are not favorable, a rock infiltration gallery can be used to promote slow infiltration / recharge of stored water.

Bioretention is an excellent stormwater treatment practice due to the variety of pollutant removal mechanisms including vegetative filtering, settling, evaporation, infiltration, transpiration, biological and microbiological uptake, and soil adsorption. Pollutant removal and effluent concentration data for select parameters are provided in the two tables below.

Caution: The information in the tables below will be updated in summer of 2014. Ranges will be provided rather than a single number because the data are highly variable.

Pollutant removal percentages for bioretention BMPs. Source Winer, 2000.

Link to this table

Practice	TSS	Total Phosphorus	Total nitrogen	Metals[1]	Bacteria	Hydrocarbons
Bioretention	85[2]	• 100 for water that is infiltrated • see [3] for water that passes through an underdrain • 0 for water bypassing the bioretention BMP	50	95	35[2]	80

[1] Average of zinc and copper

[2] Assumed values based on filtering practice performance

Typical pollutant effluent concentrations, in milligrams per liter, for bioretention BMPs. Source Winer, 2000..

Link to this table

Practice	TSS	TP	TN	Cu	Zn
Bioretention	11	0.3	1.1[1]	0.007	0.040

[1] Assumed values based on filtering practices

Early bioretention facilities were designed to provide water quality benefits by controlling the “first flush” event. Using highly permeable planting soils and an underdrain creates a high-rate biofilter, which can treat 90 to 95 percent (or higher) of the total annual volume of rainfall/runoff, depending on the design.

Limitations

Bioretention practices have been widely utilized for the past decade. Data suggests that these practices, when properly designed, constructed and maintained, perform well over long periods of time. However, design, construction and maintenance of these practices can be complex. In particular, maintenance personnel may need additional instruction on routine Operation and Maintenance requirements.

References

- Davidson, J.D., M. Isensee, C. Coudron, T. Bistodeau, N.J. LeFevre, and G. Oberts. 2008. Recommendations to Optimize Hydrologic Bioretention Performance for Cold Climates. WERF Project 04-DEC-13SG.
- Dietz, M.E. and Clausen, J.C. 2006. *Saturation to improve pollutant retention in a rain garden*. Environmental Science and Technology. Vol. 40. No. 4. pp. 1335-1340.
- Kahn, U.T., C. Valeo, A. Chu, and B. van Duin. 2012. *Bioretention cell efficacy in cold climates: Part 2 — water quality performance*. Canadian Journal of Civil Engineering. 39(11):1222-1233.
- LeFevre, N.J., J. D. Davidson, and G. L. Oberts. 2009. *Bioretention of Simulated Snowmelt: Cold Climate Performance and Design Criteria*. Proceedings of the 14th Conference on Cold Regions Engineering.
- Roseen, R.M., Ballestro, T.P., Houle, J.J., Avelleneda, P., Briggs, J., Fowler, G., and Wildey, R. 2009. *Seasonal Performance Variations for Storm-Water Management Systems in Cold Climate Conditions*. Journal of Environmental Engineering. Vol. 135. No. 3. pp. 128-137.
- Toronto and Region Conservation (TRCA). 2008. Performance Evaluation of Permeable Pavement and a Bioretention Swale, Seneca College, King City, Ontario. Prepared under the Sustainable Technologies Evaluation Program (STEP). Toronto, Ontario.

Design criteria for bioretention

Green Infrastructure: Bioretention practices can be an important tool for retention and detention of stormwater runoff. Because they utilize vegetation, bioretention practices provide additional benefits, including cleaner air, carbon sequestration, improved biological habitat, and aesthetic value.

The following terminology is used throughout this "Design Section":

Warning: *REQUIRED* - Indicates design standards stipulated by the MPCA Construction General Permit (CGP) or other consistently applicable regulations

HIGHLY RECOMMENDED - Indicates design guidance that is extremely beneficial or necessary for proper functioning of the bioretention practice, but not specifically required by the MPCA CGP.

RECOMMENDED - Indicates design guidance that is helpful for bioretention practice performance but not critical to the design.

Major design elements

Physical feasibility initial check

Before deciding to use a bioretention practice for stormwater management, it is helpful to consider several items that bear on the feasibility of using such a device at a given location. The following list of considerations will help in making an initial judgment as to whether or not a bioretention practice is the appropriate BMP for the site.

- **Drainage Area**:

The *RECOMMENDED* maximum drainage area is typically 5 acres, but can be greater if the discharge to the basin has received adequate pretreatment and the basin is properly designed, constructed, and maintained. For larger sites, multiple bioretention areas can be used to treat site runoff provided appropriate grading is present to convey flows.

For more information on contributing area, see Contributing drainage area to stormwater BMPs.

- **Site Topography and Slopes**: It is *RECOMMENDED* that sloped areas immediately adjacent to the bioretention practice be less than 33 percent but greater than 1 percent to promote positive flow towards the practice.
- **Soils**: No restrictions; engineered media *HIGHLY RECOMMENDED*; underdrain is *HIGHLY RECOMMENDED* where parent soils are HSG C or D.
- **Depth to Ground Water and Bedrock**:

Warning: A separation distance of 3 feet is REQUIRED between the bottom of the bioretention practice and the elevation of the seasonally high water table (saturated soil) or top of bedrock (i.e. there must be a minimum of 3 feet of undisturbed soil beneath the infiltration practice and the seasonally high water table or top of bedrock). Note that if underlying soils are ripped to alleviate compaction, the requirement is a 2 foot minimum between the bottom of the ripped zone and a 3 foot minimum from the bottom of the infiltration practice. If there is only a 3 foot separation distance between the bottom of the infiltration practice and the elevation of the seasonally high water table or bedrock, limit ripping depth to 12 inches.

- **Karst**: It is *HIGHLY RECOMMENDED* that bioinfiltration practices not be used in active karst formations without adequate geotechnical assessment. Underdrains and an impermeable liner may be desirable in some karst areas.
- **Wellhead Protection Areas**: It is HIGHLY RECOMMENDED to review the Stormwater and wellhead protection regarding stormwater infiltration in Wellhead Protection Areas.
- **Site Location / Minimum Setbacks**:

Warning: The minimum setback distance from a stormwater infiltration system to a community public water-supply well is 50 feet as *REQUIRED* by the Minnesota Department of Health. The setback is 35 feet to all other water-supply wells.

Caution: The minimum setbacks in the table below are *HIGHLY RECOMMENDED* for the design and location of infiltration practices. It will be necessary to consult local ordinances for further guidance on siting infiltration practices.

It is *HIGHLY RECOMMENDED* that bioinfiltration practices not be hydraulically connected to structure foundations or pavement to avoid seepage and frost heave concerns, respectively. If groundwater contamination is a concern, it is *RECOMMENDED* that

groundwater mapping be conducted to determine possible connections to adjacent groundwater wells. The table below provides the minimum recommended setbacks for the design and location of bioretention practices.

Recommended minimum setback requirements. This represents the minimum distance from the infiltration practice to the structure of concern. If the structure is aboveground, the distance is measured from the edge of the permeable pavement to the structure. If the structure is underground, the setback distance represents the distance from the point of infiltration through the bottom of the permeable pavement system to the structure.
Link to this table

Setback from	Minimum Distance [feet]
Property Line	10
Building Foundation*	10
Private Well	50
Septic System Tank/Leach Field	35
* Minimum with slopes directed away from the building.	

Conveyance

It is *Highly Recommended* that the designer provides non-erosive flow velocities at the outlet point to reduce downstream erosion. During the 10-year or 25-year storm (depending on local drainage criteria), discharge velocity should be kept below 4 feet per second for established grassed channels. Erosion control matting or rock should be specified if higher velocities are expected.

Common overflow systems within the structure consist of a yard drain inlet, where the top of the yard drain inlet is placed at the elevation of the shallow ponding area. A stone drop of about 12 inches or small stilling basin could be provided at the inlet of bioretention areas where flow enters the practice through curb cuts or other concentrated flow inlets. In cases with significant drop in grade this erosion protection should be extended to the bottom of the facility.

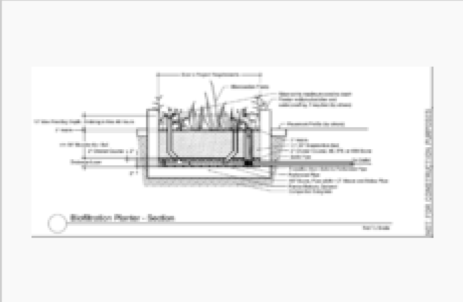
Underdrains

The following are *RECOMMENDED* for infiltration practices with underdrains.

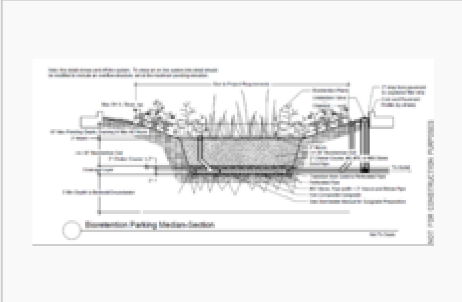
- The minimum pipe diameter is 4 inches.
- Install 2 or more underdrains for each infiltration system in case one clogs. At a minimum provide one underdrain for every 1,000 square feet of surface area.
- Include at least 2 observation /cleanouts for each underdrain, one at the upstream end and one at the downstream end. Cleanouts should be at least 4 inches diameter vertical non-perforated schedule 40 PVC pipe, and extend to the surface. Cap cleanouts with a watertight removable cap.
- Construct underdrains with Schedule 40 or SDR 35 smooth wall PVC pipe.
- Install underdrains with a minimum slope of 0.5 percent, particularly in HSG D soils (Note: to utilize Manning's equation the slope must be greater than 0).
- Include a utility trace wire for all buried piping.
- For underdrains that daylight on grade, include a marking stake and animal guard;
- For each underdrain have an accessible knife gate valve on its outlet to allow the option of operating the system as either an infiltration system, filtration system, or both. The valve should enable the ability to make adjustments to the discharge flow so the sum of the infiltration rate plus the under-drain discharge rate equal a 48 hour draw-down time.
- Perforations should be 3/8 inches. Use solid sections of non-perforated PVC piping and watertight joints wherever the underdrain system passes below berms, down steep slopes, makes a connection to a drainage structure, or daylights on grade.
- Spacing of collection laterals should be less than 25 feet.
- Underdrain pipes should have a minimum of 3 inches of washed #57 stone above and on each side of the pipe (stone is not required below the pipe). Above the stone, two inches of choking stone is needed to protect the underdrain from blockage.
- Avoid filter fabric.
- Pipe socks may be needed for underdrains imbedded in sand. If pipe socks are used, then use circular knit fabric.

The procedure to size underdrains is typically determined by the project engineer. An example for sizing underdrains is found in Section 5.7 of the North Carolina Department of Environment and Natural Resources Stormwater BMP Manual. Underdrain spacing can be calculated using the following spreadsheet, which utilizes the vanSchilfgaarde Equation. The spradsheet includes an example calculation. File:Underdrain spacing calculation.xlsx

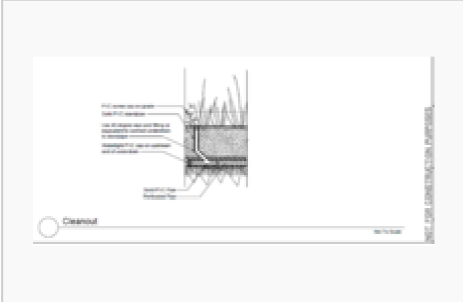
Section drawings for different bioretention devices showing several underdrain features discussed above. Click on an image for enlarged view. Also see Bioretention plan and section drawings.



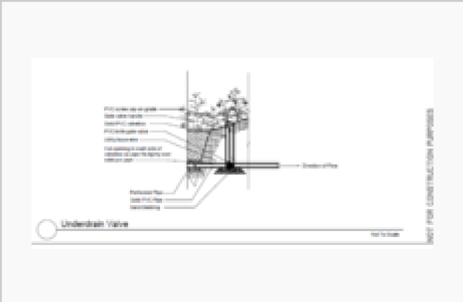
Biofiltration planter section



Bioretention parking median section



Bioretention cleanout



Bioretention underdrain valve

Pretreatment

Pretreatment refers to features of a bioretention area that capture and remove coarse sediment particles.

Warning: To prevent clogging of the infiltration or filtration system with trash, gross solids, and particulate matter, use of a pretreatment device such as a vegetated filter strip, vegetated swale, small sedimentation basin (forebay), or water quality inlet (e.g., grit chamber) to settle particulates before the stormwater discharges into the infiltration or filtration system is REQUIRED.

For applications where runoff enters the bioretention system through sheet flow, such as from parking lots, or residential back yards, a grass filter strip with a pea gravel diaphragm is the preferred pre-treatment method. The width of the filter strip depends on the drainage area, imperviousness and the filter strip slope. The minimum RECOMMENDED vegetated filter strip width is 3 feet. The

width should increase with increasing slope of the filter strip. Slopes should not exceed 8 percent. Pretreatment filter strips greater than 15 feet in width will provide diminishing marginal utility on the installation cost.

For retrofit projects and sites with tight green space constraints, it may not be possible to include a grass buffer strip. For example, parking lot island retrofits may not have adequate space to provide a grass buffer. For applications where concentrated (or channelized) runoff enters the bioretention system, such as through a slotted curb opening, a grassed channel with a pea gravel diaphragm is the preferred pre-treatment method.

The bioretention practice should be inspected semi-annually to determine if accumulated sediment needs to be removed. Accumulated sediment should be removed from the gravel verge (if applicable) and vegetated filter strip as needed. If the watershed runoff is especially dirty, this frequency may need to be monthly or quarterly. Trash removal should occur in conjunction with removal of debris from the bioretention cell. During maintenance, check for erosion in the filter strip. If it is visible, it should be repaired with topsoil and re-planted. Vegetation of the filter strip should be designed at least 2 inches below the contributing impervious surface. If, over time, the grade of the vegetated filter strip rises above the adjacent impervious surface draining into it, the grade of the vegetated filter strip needs to be lowered to ensure proper drainage.

The type of vegetation in the bioretention cell determines the appropriate flow velocity for which the pre-treatment device should be designed. For tree-shrub-mulch bioretention cells, velocity through the pre-treatment device should not exceed 1 foot per second, which is the velocity that causes incipient motion of mulch. For grassed bioretention cells, flow velocity through the pre-treatment device should not exceed 3 feet per second. In all cases, appropriate maintenance access should be provided to pre-treatment devices.

In lieu of grass buffer strips, pre-treatment may be accomplished by other methods such as sediment capture in the curb-line entrance areas. Additionally,

Pre-treatment concept developed by the City of Eagan, modified and implemented by the City of St. Cloud. Two 5 inch by 40 inch channel drains bolted to the back of the curb. Construction adhesive used where concrete and drains meet; weep holes drilled in bottom of drains. Maintenance completed by removing screws with cordless drill, then the grates and scooping out sediment/debris. Hex head

the parking lot spaces may be used for a temporary storage and pre-treatment area in lieu of a grass buffer strip. If bioretention is used to treat runoff from a parking lot or roadway that is frequently sanded during snow events, there is a high potential for clogging from sand in runoff. Local requirements may allow a street sweeping program as an acceptable pre-treatment practice. It is *HIGHLY RECOMMENDED* that pre-treatment incorporate as many of the following as are feasible:

screws required. this is a cost-effective BMP for small surface infiltration practices and can be easily used for retrofits. Photo courtesy of the City of St. Cloud.

- grass filter strip;
- vegetated swale;
- gravel diaphragm;
- mulch layer;
- forebay;
- flow-through structures; and
- up flow inlet for storm drain inflow.

Treatment

The following guidelines are applicable to the actual treatment area of a bioretention practice:

- **Space Required:** It is *RECOMMENDED* that approximately 5 to 10 percent of the tributary impervious area be dedicated to the practice footprint; with a minimum 200 square foot area for small sites (equivalent to 10 feet x 20 feet). The surface area of all infiltration designed bioretention practices is a function of MPCA's 48-hour drawdown requirement and the infiltration capacity of the underlying soils.
- **Practice Slope:** It is *RECOMMENDED* that the slope of the surface of the bioretention practice not exceed 1 percent, to promote even distribution of flow throughout.
- **Side Slopes:** It is *HIGHLY RECOMMENDED* that the maximum side slopes for an infiltration practice is 3:1 (h:v).
- **Depth:** Ponding design depths have been kept to a minimum to
  - limit depth and duration of submergence of plants improve plant survivability;
  - reduce mosquito habitat;
  - minimize compaction of in-situ soils;
  - minimize clogging;
  - maximize contact time;

- enhance safety by preventing drowning; and
- maintain aesthetic value of the bioretention system

When the drawdown time for a bioinfiltration system is 48 hours, the maximum ponding depth is

- 18 inches for Hydrologic Soil Group (HSG) A soils;
- 18 inches for SM (HSG B) soils;
- 14.4 inches for loam, silt loam and MH (HSG B) soils; and
- 9.6 inches for HSG C soils.

If field tested rates for any soil exceed the rate for A soils in the manual (1.63 inches per hour), the maximum ponding depth is 18 inches. When the drawdown time is 24 hours, the above maximum ponding depths are reduced by a factor of 2.

Warning: Permittees must provide at least one soil boring, test pit or infiltrometer test in the location of the infiltration practice for determining infiltration rates.

The Construction Stormwater General Permit requires that on-site soil testing be consistent with the Minnesota Stormwater Manual. If the permit requirement is not applicable and the recommended number of soil tests have not been taken within the boundary of the SCM, it is *Highly Recommended* the maximum ponding depth be 6 inches. Drawdown time is the time from the high water level in the practice to 1 to 2 inches above the bottom of the facility at the lowest part of the bioretention system. It is *RECOMMENDED* that the elevation difference from the inflow to the outflow be approximately 4 to 6 feet when an underdrain is used.

Warning: The *REQUIRED* drawdown time for bioretention practices is 48 hours or less from the peak water level in the practice.

Caution: It is *HIGHLY RECOMMENDED* that the drawdown time for bioretention practices is 24 hours or less from the peak water level in the practice when discharges are to a trout stream.

Warning: It is *REQUIRED* that the design permeability rate through the planting soil bed be high enough to fully drain the stormwater quality design storm runoff volume within 48 hrs.

It is *HIGHLY RECOMMENDED* that the soil permeability rate be determined by field testing.

- **Groundwater Protection:** Infiltration of unfiltered PSH runoff into groundwater should never occur; the CGP specifically prohibits inflow from “designed infiltration systems from industrial areas with exposed significant materials or from vehicle fueling and maintenance areas”.

It is *HIGHLY RECOMMENDED* that bioretention not be used on sites with a continuous flow from groundwater, sump pumps, or other sources so that constant saturated conditions do not occur.

Warning: It is *REQUIRED* that impervious area construction is completed and pervious areas established with dense and healthy vegetation prior to introduction of stormwater into a bioretention practice.

It is *HIGHLY RECOMMENDED* that soils meet the design criteria outlined later in this section and contain less than 5 percent clay by volume. Elevations must be carefully worked out to ensure that the desired runoff flow enters the facility with no more than the maximum design depth. The bioretention area (A_f) should be sized based on the principles discussed below.

Landscaping

Warning: It is *REQUIRED* that impervious area construction is completed and pervious areas established with dense and healthy vegetation prior to introduction of stormwater into a vegetated infiltration practice.

Landscaping is critical to the performance and function of vegetated areas of infiltration practices. Therefore, a landscaping plan is *HIGHLY RECOMMENDED* for vegetated infiltration practices. *RECOMMENDED* planting guidelines for vegetated practices are as follows:

- Vegetation should be selected based on a specified zone of hydric tolerance. *Plants for Stormwater Design - Species selection for the Upper Midwest* is a good resource.
- Native plant species should be specified over non-native species. Hardy native species that thrive in our ecosystem without chemical fertilizers and pesticides are the best choices.
- Many vegetated practices feature wild flowers and grasses as well as shrubs and some trees.

- If woody vegetation is placed near inflow locations, it should be kept out of pretreatment devices and be far enough away to not hamper maintenance of pretreatment devices.
- Trees should not be planted directly overtop of under-drains and may be best located along the perimeter of the practice.
- Salt resistant vegetation should be used in locations with probable adjacent salt application, i.e. roadside, parking lot, etc.
- Plugs, bare root plants or potted plants are RECOMMENDED over seed for herbaceous plants, shrubs, and trees. Erosion control mats pre-vegetated with herbaceous plants are also acceptable. For turf, sod is recommended over seed. (NOTE: Fluctuating water levels following seeding (prior to germination) can cause seed to float and be transported, resulting in bare areas that are more prone to erosion and weed invasion than vegetated areas. Seed is also difficult to establish through mulch, a common surface component of vegetated practices. It may take more than two growing seasons to establish the function and desired aesthetic of mature vegetation via seeding.)
- Vegetated practices should be operated off-line for 1 year or, within the first year, until vegetation is established.
- Example target plant coverage includes
  - at least 50 percent of specified vegetation cover at end of the first growing season;
  - at least 90 percent of specified vegetation cover at end of the third growing season;
  - supplement plantings to meet project specifications if cover targets are not met; and
  - tailoring percent coverage targets to project goals and vegetation. For example, percent cover required for turf after 1 growing season would likely be 100 percent, whereas it would likely be lower for other vegetation types.
- Vegetated areas should be integrated into the site planning process, and aesthetic considerations should be taken into account in their siting and design.

Operation and maintenance of vegetated practices is critical to meeting these landscape recommendations and targets. For more information on operation and maintenance, see the section on operation and maintenance of stormwater infiltration practices.

Safety

Bioretention practices do not pose any major safety hazards. Trees and the screening they provide may be the most significant consideration of a designer and landscape architect. Where inlets exist, they should have grates that either have locks or are sufficiently heavy that they cannot be removed easily. Standard inlets and grates used by Mn/DOT and local jurisdictions should be adequate. Fencing of bioretention facilities is generally not desirable.

Maximum flow path

Flow path length is important only if high flows are not bypassed. Below are recommendations from other states or localities.

- North Carolina: The geometry of the cell shall be such that width, length, or radius are not less than 10 feet. This is to provide sufficient space for plants.
- Virginia: Length of shortest flow path to overall length is 0.3 for Level 1 Design and 0.8 for Level 2 Design
- Dakota County Soil and Water Conservation District: Where off-line designs are not achievable, bioretention practices shall be designed to route high flows on the shortest flow path across the cell to provide the least disturbance and displacement of the Water Quality Volume to be treated. Energy dissipation to avoid high flow velocity turbulence is required.

Use of multiple cells

In comparison to multiple cells, one large bioretention or infiltration cell will often perform just as well as multiple smaller cells if sized and designed appropriately. One large cell is generally less costly than multiple smaller cells. This is due to the simpler geometry and grading requirements of one large cell, as well as a reduction in piping and outlet structures. Multiple smaller cells do however provide greater redundancy, i.e. if one large cell fails, more function is lost than if just one of multiple cells fail. Multiple cells are also more feasible than one large cell in steep terrain (slopes greater than 5 percent), where they can be terraced to match the existing grade. Provided access is maintained to each cell, multiple cells typically results in less and easier maintenance.

Snow considerations

Considering management of snow, the following are recommended.

- Plan a plow path during design phase and tell snowplow operators where to push the snow. Plan trees around (not in) plow path, with a 16 foot minimum between trees.
- Plan for snow storage (both temporary during construction and permanent). Don’t plow into raingardens routinely. Raingardens should be last resort for snow storage (ie only for during very large snowevents as “emergency overflow”.
- Snow storage could be, for example, a pretreatment moat around a raingarden, i.e. a forebay for snow melt.

Materials specifications - filter media

Filter media depth

Research has shown that minimum bioretention soil media depth needed varies depending on the target pollutant(s). The table below summarizes the relationship between media depth and pollutant attenuation. In general, the *Recommended* filter media depth is 2.5 feet or more to allow adequate filtration processes to occur.

Information: The Recommended filter media depth is 2.5 feet or more to allow adequate filtration processes to occur

Minimum bioretention soil media depths recommended to target specific stormwater pollutants. From Hunt et al. (2012) and Hathaway et al., (2011).

Link to this table

Pollutant	Depth of Treatment with upturned elbow or elevated underdrain	Depth of Treatment without underdrain or with underdrain at bottom	Minimum depth
Total suspended solids (TSS)	Top 2 to 3 inches of bioretention soil media	Top 2 to 3 inches of bioretention soil media	Not applicable for TSS because minimum depth needed for plant survival and growth is greater than minimum depth needed for TSS reduction
Metals	Top 8 inches of bioretention soil media	Top 8 inches of bioretention soil media	Not applicable for metals because minimum depth needed for plant survival and growth is greater than minimum depth needed for metals reduction
Hydrocarbons	3 to 4 inch Mulch layer, top 1 inch of bioretention soil media	3 to 4 inches Mulch layer, top 1 inch of	Not applicable for hydrocarbons because minimum depth needed for plant survival and growth is

		bioretention soil media	greater than minimum depth needed for hydrocarbons reduction
Nitrogen	From top to bottom of bioretention soil media; Internal Water Storage Zone (IWS) improves exfiltration, thereby reducing pollutant load to the receiving stream, and also improves nitrogen removal because the longer retention time allows denitrification to occur underanoxic conditions.	From top to bottom of bioretention soil media	Retention time is important, so deeper media is preferred (3 foot minimum)
Particulate phosphorus	Top 2 to 3 inches of bioretention soil media.	Top 2 to 3 inches of bioretention soil media.	Not applicable for particulate phosphorus because minimum depth needed for plant survival and growth is greater than minimum depth needed for particulate phosphorus reduction
Dissolved phosphorus	From top of media to top of submerged zone. Saturated conditions cause P to not be effectively stored in submerged zone.	From top to bottom of bioretention soil media	Minimum 2 feet, but 3 feet recommended as a conservative value; if IWS is included, keep top of submerged zone at least 1.5 to 2 feet from surface of media
Pathogens	From top of soil to top of submerged zone.	From top to bottom of bioretention soil media	Minimum 2 feet; if IWS is included, keep top of submerged zone at least 2 feet from surface of media
Temperature	From top to bottom of bioretention soil media; Internal Water Storage Zone (IWS) improves exfiltration, thereby reducing volume of warm runoff discharged to the receiving stream, and also improves thermal pollution abatement because the longer retention time allows runoff to cool more before discharge.	From top to bottom of bioretention soil media	Minimum 3 feet, with 4 feet preferred

Performance specifications

The following performance specifications are applicable to all bioretention media.

- Growing media must be suitable for supporting vigorous growth of selected plant species.
- The pH range (soil/water 1:1) is 6.0 to 8.5
- Soluble salts (soil/water 1:2) should not to exceed 500 parts per million
- All bioretention growing media must have a field tested infiltration rate between 1 and 8 inches per hour. Growing media with slower infiltration rates could clog over time and may not meet drawdown requirements. Target infiltration rates should be no more than 8 inches per hour to allow for adequate water retention for vegetation as well as adequate retention time for pollutant removal. The following infiltration rates should be achieved if specific pollutants are targeted in a watershed.
    - Total suspended solids: Any rate is sufficient, 2 to 6 inches recommended
    - Pathogens: Any rate is sufficient, 2 to 6 inches recommended
    - Metals: Any rate is sufficient, 2 to 6 inches recommended
    - Temperature: slower rates are preferable (less than 2 inches per hour)
    - Total nitrogen (TN): 1 to 2 inches per hour, with 1 inch per hour recommended
    - Total phosphorus (TP): 2 inches per hour

The following additional bioretention growing media performance specifications are required to receive P reduction credit.

- Option A - use bioretention soil with phosphorus content between 12 and 36 mg/kg (ppm)
- Option B - use bioretention soil with a soil amendment that facilitates adsorption of phosphorus

In general, Bioretention Mixes A and B will not be suitable for achieving reductions in phosphorus loading for bioretention systems having an underdrain unless an amendment is added to the bioretention soil. For guidance on adding an amendment to a bioretention soil, see Soil amendments to enhance phosphorus sorption.

Guidance for bioretention media composition

Addressing phosphorus leaching concerns with media mixes

Caution: Biofiltration practices can export phosphorus and contribute to water quality impairments

Biofiltration practices (bioretention systems with an underdrain) return treated water to the stormwater discharge system. Bioretention media with high concentrations of organic matter can export soluble phosphorus in higher concentrations than the

incoming stormwater runoff, thus contributing to increased phosphorus loading to receiving waters. The International Stormwater BMP Database (2016), for example, shows statistically higher concentrations of dissolved phosphorus in effluent from bioretention systems compared to influent.

If biofiltration practices are implemented to reduce phosphorus loads to receiving waters, we recommend implementing one of the following recommendations.

- Test the mix for phosphorus (P) concentration. If the media phosphorus content exceeds 30 mg-P/kg-mix it is likely to export P. Consider amending the mix to lower the P content to less than 30 mg-P/kg-mix or adding a material, such as iron, to attenuate P.
- Use mix C, D, or some other mix with an organic matter content less than 5 percent by dry weight.
- Use peat or some other low-P or slow release material as the source of organic matter instead of compost.
- Use an amendment that attenuates P, such as iron. Link here to see example designs that utilize P-attenuating amendments.

Mix A: Water quality blend

A well blended, homogenous mixture of

- 60 to 70 percent construction sand;
- 15 to 25 percent top soil; and
- 15 to 25 percent organic matter.

Sand: Provide clean construction sand, free of deleterious materials. AASHTO M-6 or ASTM C-33 washed sand.

Top Soil: Sandy loam, loamy sand, or loam texture per USDA textural triangle with less than 5 percent clay content

Organic Matter: MnDOT Grade 2 compost (See Specification 3890, page 685) is recommended.

It is assumed this mix will leach phosphorus. When an underdrain is utilized a soil phosphorus test is needed to receive water quality credits for the portion of stormwater captured by the underdrain. The phosphorus index (P-index) for the soil must be low, between 10 and 30 milligrams per kilogram when using the Mehlich-3 (or equivalent) test. This is enough phosphorus to support plant growth without exporting phosphorus from the cell.

Mix B: Enhanced filtration blend

A well-blended, homogenous mixture of

- 70 to 85 percent construction sand; and
- 15 to 30 percent organic matter.

  Sand: Provide clean construction sand, free of deleterious materials. AASHTO M-6 or ASTM C-33 washed sand.

  Top Soil in the mix will help with some nutrient removal, especially nutrients, but extra care must be taken during construction to inspect the soils before installation and to avoid compaction.

  Organic Matter: MnDOT Grade 2 compost (See Specification 3890, page 685) is recommended.

It is assumed this mix will leach phosphorus. When an underdrain is utilized a soil phosphorus test is needed to receive water quality credits for the portion of stormwater captured by the underdrain. The phosphorus index (P-index) for the soil must be low, between 10 and 30 milligrams per kilogram when using the Mehlich-3 (or equivalent) test. This is enough phosphorus to support plant growth without exporting phosphorus from the cell.

Mix C: North Carolina State University water quality blend

Source: North Carolina Department of Environment and Natural Resources, 2009. See Section 12.3.4

This mix is a homogenous soil mix of

- 85 to 88 percent by volume sand (USDA Soil Textural Classification);
- 8 to 12 percent fines by volume (silt and clay, with a maximum clay content of 5% recommended); and
- 3 to 5 percent organic matter by volume (ASTM D 2974 Method C) MnDOT Grade 2 compost (See Specification 3890, page 685) is recommended.

A higher concentration of fines (12 percent) should be reserved for areas where nitrogen is the target pollutant. In areas where phosphorus is the target pollutant, a lower concentration of fines (8 percent) should be used. A soil phosphorus test using the Mehlich-3 (or equivalent) method is recommended but not required to receive water quality credits. The phosphorus index (P-index) for the soil must be low, between 10 and 30 milligrams per kilogram. This is enough phosphorus to support plant growth without exporting phosphorus from the cell. It is assumed this mix will not exceed the upper range of recommended values (30 milligrams per kilogram), although at lower concentrations of organic matter a soil test may be needed to confirm there is adequate phosphorus for plant growth.

Mix D

Caution: If phosphorus is a water quality concern for receiving waters, Bioretention Mix D (as well as Mix C) is recommended when using infiltration systems having an underdrain. The following discussion provides general guidelines for Bioretention Mix D. If using or considering Bioretention Mix D, please see specific guidelines for this mix to avoid confusion with Mixes A, B, and C.

Bioretention Soil Mix D soil shall be a mixture of coarse sand, compost and topsoil in proportions which meet the following:

- silt plus clay (combined): 25 to 40 percent, by dry weight
- total sand: 60 to 75 percent, by dry weight
- total coarse and medium sand: minimum of 55 percent of total sand, by dry weight
- fine gravel less than 5 millimeters: up to 12 percent by dry weight (calculated separately from sand/silt/ clay total)
- organic matter content: 2 to 5 percent, percent loss on ignition by dry weight; MnDOT Grade 2 compost (See Specification 3890, page 685) is recommended.
- saturated hydraulic conductivity: 1 to 4 inches per hour ASTM F1815. Note that although this infiltration rate is generally applicable at 85 percent compaction, Standard Proctor ASTM D968, this is an infiltration rate standard and not a compaction standard. Therefore, this infiltration rate may be met at lower levels of compaction.

Suggested mix ratio ranges, by volume, are

- Coarse sand: 50 to 65 percent
- Topsoil: 25 to 35 percent
- Compost (assuming MnDOT Grade 2 compost is being used): 10 to 15 percent. Note this yields an organic matter content of approximately 2 to 5 percent.

Note that the above mix ratios are on a volume basis rather than a weight basis. See specific guidance on these.

A soil phosphorus test using the Mehlich-3 (or equivalent) method is recommended but not required to receive water quality credits. The phosphorus index (P-index) for the soil must be low, between 10 and 30 milligrams per kilogram. This is enough phosphorus to support plant growth without exporting phosphorus from the cell. It is assumed this mix will not exceed the upper range of recommended values (30 milligrams per kilogram), although at lower concentrations of organic matter a soil test may be needed to confirm there is adequate phosphorus for plant growth.

Mix E: MnDOT 3877.2 Type G 'Filter Topsoil Borrow'

A well-blended, homogenous mixture of

- 60 to 80 percent sand meeting gradation requirements of 3126, "Fine Aggregate for Portland Cement Concrete"; and
- 20 to 40 percent compost meeting requirements 3890 Grade 2 Compost.

Provide topsoil borrow containing two blended components of sand and compost for water quality, plant growing medium, and filtration medium with a filtration rate of at least 4 inches per hour [10 centimeters per hour].

See page 672 of MnDOT Standard Specifications for Construction

Mix F: Custom Infiltration Basin Planting Soil

This mix is a homogenous soil mix of

- 75 percent by weight loamy sand (USDA Soil Textural Classification based on grain size); and
- 25 percent by weight MnDOT grade 2 compost (See page 687 of Standard Specifications for Construction, Specification 3890).

Loamy sand as determined by the USDA soil texture classification based on grain size. Loamy sand is defined as soil material that contains at the upper limit 85 to 90 percent sand, and the percentage of silt plus 1.5 times the percentage of clay is not less than 15. At the lower limit it contains not less than 70 to 85 percent sand, and the percentage of silt plus twice the percentage of clay does not exceed 30. In addition, the maximum particle size shall be less than 1-inch.

Comparison of pros and cons of bioretention soil mixes

Link to this table.

Mix	Composition in original Manual	Proposed updated composition	Pros	Cons
A	• 55-65% construction sand • 10-20% top soil • 25-35% organic matter[2]	• 60-70% construction sand • 15-25% top soil • 15-25% organic matter[2] • to receive P credit for water captured by underdrain the P content must be less than 30 mg/kg (ppm) per Mehlich III (or equivalent) test; NOTE a minimum P concentration of	Likely to sorb more dissolved P and metals than mix B because it contains some fines; best for growth of most plants	Likely to leach P; if topsoil exceeds maximum allowed clay content, higher fines content could result in poor hydraulic performance and long drawdown times

		12 mg/kg is recommended for plant growth.		
B	• 50-70% construction sand • 30-50% organic matter	• 70-85% construction sand • 15-30% organic matter • to receive P credit for water captured by underdrain the P content must be less than 30 mg/kg per Mehlich III (or equivalent) test; NOTE a minimum P concentration of 12 mg/kg is recommended for plant growth.	Easy to mix; least likely to clog	Likely to leach P, lack of fines in mix results in less dissolved pollutant removal; harder on most plants than mix A because it dries out very quickly
C	Not in original MN Stormwater Manual	• 85-88 percent by volume sand and • 8 to 12 percent fines by volume, • 3 to 5 percent organic matter by volume • recommended P content between 12 and 30 mg/kg per Mehlich III (or equivalent) test	Likely to sorb more dissolved P and metals than mix B because it contains some fines; less likely to leach P than mix B because of low P content	Harder on most plants than mix A because it dries out very quickly. Research in Wisconsin indicates that in cold climates, excess of Na ions can promote displacement of Mg and Ca in the soil, which breaks down soil structure and decreases infiltration rate, and can also cause nutrient imbalances[1]
D	Not in original MN Stormwater Manual	• All components below by dry weight: • 60-75% sand • Min. 55% total coarse and medium sand as a % of total sand • Less than 12% fine gravel less than 5 mm (Calculated	Best for pollutant removal, moisture retention, and growth of most plants; less likely to leach P than mix B because of low P content	Harder to find. Research in Wisconsin indicates that in cold climates, excess of Na ions can promote displacement of Mg and Ca in the soil, which breaks down soil structure and decreases infiltration rate, and can also cause nutrient imbalances

		separately from sand/silt/ clay total) • 2 to 5 % organic matter • recommended P content between 12 and 30 mg/kg per Mehlich III (or equivalent) test		
E	Not in original manual	• 60-80% sand meeting gradation requirements of MnDOT 3126, —Fine Aggregate for Portland Cement Concrete • 20-40% MnDOT 3890 Grade 2 Compost • 30% organic leaf compost	High infiltration rates, relatively inexpensive	As compost breaks down, nutrients available for plants decreases
F	Not in original manual	• 75% loamy sand by volume: ◦ Upper Limit: 85-90% sand with %Silt + 1.5 times %Clay > 15%. ◦ Lower Limit: 70-85% sand with %Silt + 2 times %Clay < 30%. ◦ Maximum particle size < 1-inch • 25% MnDOT 3890 Grade 2 Compost	Finer particles in loamy sand holds moisture for better plant growth	Lower infiltration rates, requires careful soil placement to avoid compaction, requires custom mixing

[1]This problem can be avoided by minimizing salt use. Sodium absorption ratio (SAR) can be tested; if the SAR becomes too high, additions of gypsum (calcium sulfate) can be added to the soil to free the Na and allow it to be leached from the soil (Pitt et al in press).

[2]MnDOT Grade 2 compost is recommended.

Notes about soil phosphorus testing: applicability and interpretation

The Mehlich III phosphorus test is specified throughout the Manual, with the stipulation that other soil P tests may be acceptable. Other common P tests used by soil testing laboratories are the Bray and Olsen tests. These tests are acceptable substitutes for the Mehlich III test, with the exception that the Bray test should not be used in calcareous soils or those with a pH greater than 7.3. If in doubt, ask your soil testing laboratory to recommend the appropriate test.

If the pH and non-calcareous conditions are met, the numerical results of the Bray test can be considered equal to those of the Mehlich III test for the purposes of assessing bioretention mixes and other recommendations or requirements stated in the Manual (e.g., if less than 30 milligrams per kilogram by the Mehlich III test is specified to receive the P credit, then the Bray test result should be less than 30 milligrams per kilogram if the Bray test is substituted). The equivalent Olsen test result is lower, such that if 30 milligrams per kilogram or less by the Mehlich test is specified, then an Olsen test result of 20 milligrams per kilogram or less is necessary to receive the P credit. In general, most guidance interprets Olsen test results at a ratio of approximately 2:3 of those of Bray and Mehlich III, with Bray and Mehlich III being roughly equivalent to each other. For example, a Mehlich III result of 9 milligrams per kilogram would be equivalent to 9 milligrams per kilogram by Bray (as long as pH is less than 7.3) and equivalent to 6 milligrams per kilogram by Olsen.

For more information on the relationships between these P tests, see "Differentiating and Understanding the Mehlich 3, Bray, and Olsen Soil Phosphorus Tests", by Sawyer and Mallarino (1999).

Other media

Several other media are currently being tested. A few examples are listed below.

Wisconsin peat moss replacement (Bannerman, 2013)

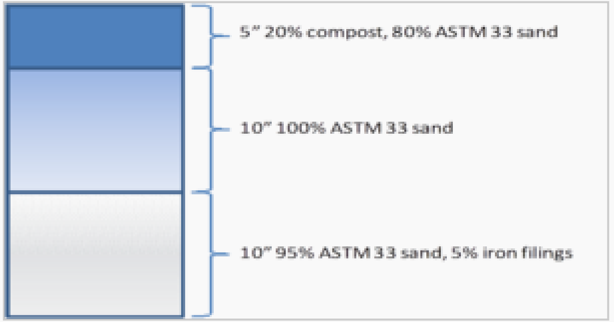
The following mix utilizes peat moss instead of compost.

- 12 percent peat moss
- 2 percent Imbrium Sorptive®MEDIA
- 86 percent sand

This mix aims to maximize phosphorus removal in 2 ways:

- substituting peat moss for compost, since peat moss has lower phosphorus content than compost and does not leach phosphorus; and
- including Sorptive®MEDIA to sorb phosphorus and minimize phosphorus in effluent

Layered systems



Section showing Wisconsin layered system with compost only in top 5 inches and iron filings in 10 inch deep layer at the bottom of the system

Several researchers are currently testing layered systems designed to minimize phosphorus in bioretention effluent. The Wisconsin layered system utilizes a 5 inch surface layer containing 20 percent compost, a 10 inch sand layer below the top layer, and a 10 inch lower layer containing 5 percent iron filings. Advantages of this system include

- compost is used only where it is needed for soil water retention for healthy plant growth. Using sand without compost below the top five inches of the soil profile, where vegetation does not need compost, minimizes total compost volume in the system, and thereby reduces potential for leaching of phosphorus from compost; and
- iron filings in bottom layers sorb phosphorus.

Disadvantages include

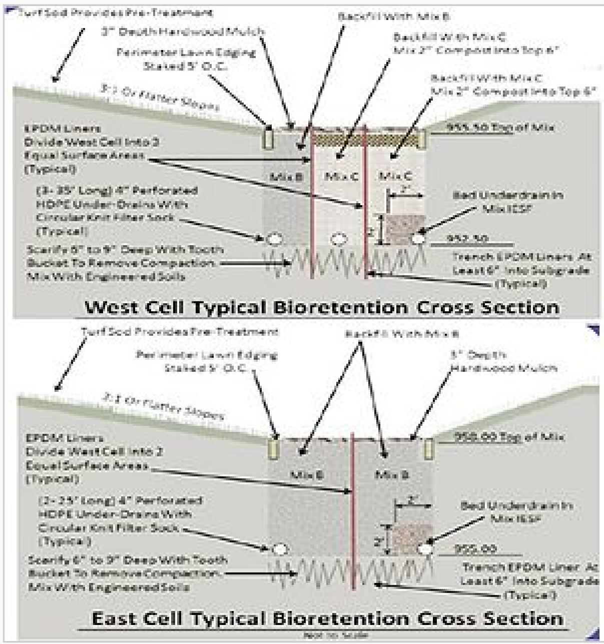
- higher cost due to layering;
- greater potential for installation error compared to a system that is not layered; and
- plants may not grow as vigorously because soil water holding capacity will be very low below the top 5 inches of soil, since there is no organic matter below that depth.

Dakota County developed a layered system with compost only in top six inches, 20 percent coir pith, and 5 percent iron filings in the bottom layer (Isensee 2013). Advantages of this mix include:

- compost is used only where it is needed for soil water retention for healthy plant growth. Using sand without compost below the top foot of the soil profile, where vegetation does not need compost, minimizes total compost volume in the system, and thereby reduces potential for leaching of P from compost.
- iron filings in bottom layers sorb P; and
- coir supplements organic matter provided by compost but does not leach P.

Disadvantages include:

- higher cost due to layers; and
- greater potential for installation error compared to a system that is not layered.Dakota County is monitoring these bioretention systems, which were installed in fall of 2012.



Sections showing Dakota County layered systems with compost only in top six inches, 20 percent coir pith, and 5 percent iron filings in bottom layer (From Dakota County Soil and Water Conservation District 2012). Mix B is 70 percent washed sand/30 percent compost; Mix C is 80 percent washed sand/20 percent coir pith; Mix IESF is 95 percent washed sand/5 percent iron filings. each cell is 3 feet deep.

Design procedure - design steps

The following steps outline a recommended design procedure for bioretention practices in compliance with the MPCA Construction General Permit for new construction. Design recommendations beyond those specifically required by the permit are also included and marked accordingly.

Step 1: Make a preliminary judgment

Make a preliminary judgment as to whether site conditions are appropriate for the use of an infiltration practice, and identify the function of the practice in the overall treatment system.

A. Consider basic issues for initial suitability screening, including:

- site drainage area (See the **Summary of infiltration practices for given drainage areas** table below);
- site topography and slopes;
- soil infiltration capacity;
- regional or local depth to groundwater and bedrock;
- site location/ minimum setbacks; and
- presence of active karst.

B. Determine how the infiltration practice will fit into the overall stormwater treatment system.

- Decide whether the infiltration practice is the only BMP to be employed, or if are there other BMPs addressing some of the treatment requirements.
- Decide where on the site the infiltration practice is most likely to be located.

Stormwater infiltration BMPs - contributing drainage area

Link to this table

Stormwater BMP	Recommended contributing area	Notes
Infiltration Basin	50 acres or less	A natural or constructed impoundment that captures, temporarily stores and infiltrates the design volume of water into the surrounding naturally permeable soil over several days. In the case of a constructed basin, the impoundment is created by excavation or embankment.
Bioinfiltration Basin	5 acres or less	Bioinfiltration basins must meet the required 48 hour drawdown time and must be sized in order to allow for adequate maintenance. It is HIGHLY RECOMMENDED that bioinfiltration basins be designed to prevent high levels of bounce as submerging vegetation may inhibit plant growth. A maximum wet storage depth of 1.5 feet is HIGHLY RECOMMENDED.
Infiltration Trench	5 acres or less	
Dry Well Synonym: Infiltration Tube, French Drain, Soak-Away Pits, Soak Holes	1 acre or less (rooftop only)	
Underground Infiltration	10 acres or less	Though feasible, larger underground infiltration systems may cause groundwater contamination as water is not able to infiltrate through a surface cover. In addition, wind flocculation, UV degradation, and bacterial degradation, which provide additional treatment in surface systems, do not occur in underground systems. Because performance research is lacking for larger features, it is HIGHLY RECOMMENDED that the contributing drainage area to a single device not exceed 10 acres.
Dry Swale	5 acres or less	

with Check Dams		
Permeable Pavement	It is RECOMMENDED that external contributing drainage area not exceed the surface area of the permeable pavement. It is HIGHLY RECOMMENDED that external contributing drainage area not exceed twice the surface area of the permeable pavement	It is RECOMMENDED that external drainage area be as close to 100% impervious as possible. Field experience has shown that drainage area (pervious or impervious) can contribute particulates to the permeable pavement and lead to clogging. Therefore, sediment source control and/or pre-treatment should be used to control sediment run-on to the permeable pavement section.
Tree Trench/Tree Box	up to 0.25 acres per tree	

References: Virginia, North Carolina, West Virginia, Maine, Lake Tahoe, Connecticut, Massachusetts, New York, Wisconsin, Vermont, New Hampshire, Ontario, Pennsylvania

Step 2: Confirm design criteria and applicability

Determine whether the infiltration practice must comply with the MPCA Construction Stormwater General (CSW) Permit. Check with local officials, Watershed management Organizations (WMOs), and other agencies to determine if there are any additional restrictions and/or surface water or watershed requirements that may apply.

Warning: If the infiltration practice must comply with the CSW permit, the following prohibitions apply:

- areas that receive discharges from vehicle fueling and maintenance;
- areas with less than three (3) feet of separation distance from the bottom of the infiltration system to the elevation of the seasonally saturated soils or the top of bedrock;
- areas that receive discharges from industrial facilities which are not authorized to infiltrate industrial stormwater under an NPDES/SDS Industrial Stormwater Permit issued by the MPCA;
- areas where high levels of contaminants in soil or groundwater will be mobilized by the infiltrating stormwater;
- areas of predominately Hydrologic Soil Group D (clay) soils;
- areas within 1,000 feet up-gradient, or 100 feet down-gradient of active karst features;

- areas within a Drinking Water Supply Management Area (DWSMA) as defined in Minn. R. 4720.5100, subp. 13., if the system will be located:
  - in an Emergency Response Area (ERA) within a DWSMA classified as having high or very high vulnerability as defined by the Minnesota Department of Health; or
  - in an ERA within a DWSMA classified as moderate vulnerability unless a regulated MS4 Permittee performed or approved a higher level of engineering review sufficient to provide a functioning treatment system and to prevent adverse impacts to groundwater; or
  - outside of an ERA within a DWSMA classified as having high or very high vulnerability, unless a regulated MS4 Permittee performed or approved a higher level of engineering review sufficient to provide a functioning treatment system and to prevent adverse impacts to groundwater; and
- areas where soil infiltration rates are more than 8.3 inches per hour unless soils are amended to slow the infiltration rate below 8.3 inches per hour.

Step 3: Perform field verification of site suitability

Warning: The Construction Stormwater permit includes the following requirements.
16.10. Permittees must provide at least one soil boring, test pit or infiltrometer test in the location of the infiltration practice for determining infiltration rates.

16.11. For design purposes, permittees must divide field measured infiltration rates by 2 as a safety factor or permittees can use soil-boring results with the infiltration rate chart in the Minnesota Stormwater Manual to determine design infiltration rates. When soil borings indicate type A soils, permittees should perform field measurements to verify the rate is not above 8.3 inches per hour. This permit prohibits infiltration if the field measured infiltration rate is above 8.3 inches per hour.

Designers should evaluate soil properties during preliminary site layout with the intent of installing infiltration practices on soils with the highest infiltration rates (HSG A and B). Preliminary planning for the location of an infiltration device may be completed using a county soil survey or the NRCS Web Soil Survey. These publications provide HSG information for soils across Minnesota. To ensure long-term performance, however, field soil measurements are desired to provide site-specific data.

If the initial evaluation indicates that an infiltration practice would be a good BMP for the site, it is *RECOMMENDED* that soil borings or pits be dug within the proposed boundary of the infiltration practice to verify soil types and infiltration capacity characteristics and to determine the depth to groundwater and bedrock. Soil borings for building structural analysis are not acceptable. In all design scenarios, a minimum of one soil boring (two are recommended) shall be completed to a depth 5 feet below the bottom of the proposed infiltration Stormwater Control Measure (SCM or BMP) (Dakota County Soil and Water Conservation District, 2012) per ASTM D1586 (ASTM, 2011). For infiltration SCMs with surface area between 1000 and 5000 square feet, two borings shall be made. Between 5000 and 10000 square feet, three borings are needed, and for systems with greater than 10000 square feet in surface area, 4 or more borings are needed. For each additional 2500 square feet beyond 12,500 square feet, an additional soil boring should be made. Soil borings must be undertaken during the design phase (i.e. prior to the commencement of construction) to determine how extensive the soil testing will be during construction. Borings should be completed using continuous split spoon sampling, with blow counts being recorded to determine the level of compaction of the soil. Soil borings are needed to understand soil types, seasonally high groundwater table elevation, depth to karst, and bedrock elevations.

Recommended number of soil borings, pits or permeameter tests for bioretention design. Designers select one of these methods.

Link to this table

Surface area of stormwater control measure (BMP)(ft^2)	Borings	Pits	Permeameter tests
< 1000	1	1	5
1000 to 5000	2	2	10
5000 to 10000	3	3	15
>10000	4[1]	4[1]	20[2]

[1]an additional soil boring or pit should be completed for each additional 2,500 ft^2 above 12,500 ft^2

[2]an additional five permeameter tests should be completed for each additional 5,000 ft^2 above 15,000 ft^2

It is *HIGHLY RECOMMENDED* that soil profile descriptions be recorded and include the following information for each soil horizon or layer (Source: *Site Evaluation for Stormwater Infiltration*, Wisconsin Department of Natural Resources Conservation Practice Standards 2004):

- thickness, in inches or decimal feet;
- Munsell soil color notation;
- soil mottle or redoximorphic feature color, abundance, size and contrast;
- USDA soil textural class with rock fragment modifiers;
- soil structure, grade size and shape;
- soil consistence, root abundance and size;
- soil boundary; and
- occurrence of saturated soil, impermeable layers/lenses, ground water, bedrock or disturbed soil.

It is RECOMMENDED that a standard soil boring form be used. A good example is File:Boring Pit Log form.docx. The NRCS Field Book for Describing and Sampling Soils provide detailed information for identifying soil characteristics. Munsell color charts can be found at [4].

Warning: A separation distance of 3 feet is REQUIRED between the bottom of the infiltration practice and the elevation of the seasonally high water table (saturated soil) or top of bedrock (i.e. there must be a minimum of 3 feet of undisturbed soil beneath the infiltration practice and the seasonally high water table or top of bedrock).

It is HIGHLY RECOMMENDED that the field verification be conducted by a qualified geotechnical professional.

Step 4: Compute runoff control volumes

Warning: If the bioretention practice is being designed to meet the requirements of the MPCA Permit, the *REQUIRED* treatment volume is the water quality volume (V_{wq}) of 1 inch of runoff from the new impervious surfaces created from the project. If part of the overall V_{wq} is to be treated by other BMPs, subtract that portion from the V_{wq} to determine the part of the V_{wq} to be treated by the bioretention practice.

The design techniques in this section are meant to maximize the volume of stormwater being infiltrated. If the site layout and underlying soil conditions permit, a portion of the Channel Protection Volume (V_{cp}), Overbank Flood Protection Volume (V_{p10}), and the Extreme Flood Volume (V_{p100}) may also be managed in the bioretention practice.

Step 5: Determine bioretention type and size practice

(Note: Steps 5, 6, 7 and 8 are iterative)

Select Design Variant

After following the steps outlined above, the designer will presumably know the location of naturally occurring permeable soils, the depth to the water table, bedrock or other impermeable layers, and the contributing drainage area. While the first step in sizing a bioretention practice is selecting the type of design variant for the site, the basic design procedures for each type of bioretention practice are similar.

After determining the water quality volume for the entire site (Step 4), determine the portion of the total volume that will be treated by the bioretention practice. Based on the known V_{wq}, infiltration rates of the underlying soils and the known existing potential pollutant loading from proposed/existing landuse, select the appropriate bioretention practice from the table below. Note: the determination for underdrain is an iterative sizing process.

Warning: Bioretention practices shall discharge through the soil or filter media in 48 hours or less. Additional flows that cannot be infiltrated or filtered in 48 hours should be routed to bypass the system through a stabilized discharge point.

Experience has demonstrated that, although the drawdown period is 48 hours, there is often some residual water pooled in the infiltration practice after 48 hours. This residual water may be associated with reduced head, water gathered in depressions within the practice, water trapped by vegetation, and so on. The drawdown period is therefore defined as the time from the high water level in the practice to 1 to 2 inches above the bottom of the facility. This criterion was established to provide the following: wet-dry cycling between rainfall events; unsuitable mosquito breeding habitat; suitable habitat for vegetation; aerobic conditions; and storage for back-to-back precipitation events. This time period has also been called the period of inundation.

Caution: It is *HIGHLY RECOMMENDED* that the drawdown time for bioretention practices is 24 hours or less from the peak water level in the practice when discharges are to a trout stream.

Summary of Bioretention Variants for Permeability of Native Soils and Potential Land use Pollutant Loading

(Link to this table)

Bioretention Type[1]	Variant	Underlying Soil Performance Criteria
Bioinfiltration (Infiltration/Recharge Facility)	No underdrain	Higher recharge potential (facility drain time without underdrain is 48 hours or less)
Biofiltration with underdrain at the bottom (Filtration/Partial Recharge Facility)	Underdrain	Lower recharge potential (facility drain time without underdrain is > 48 hours)
Biofiltration with internal water storage	Underdrain	Lower recharge potential (facility drain time without underdrain is >48 hours)
Biofiltration with elevated underdrain (Infiltration/Filtration/Recharge Facility)	Elevated underdrain	Higher nutrient loadings and/or quantity control
Biofiltration with liner (Filtration Only Facility)	Underdrain with liner	Hot Spot Treatment

[1]The terminology has been changed from the original manual. The original Manual terminology is shown in parenthesis. For more information, see Bioretention terminology

Information collected during the Physical Suitability Evaluation (see Step 3) should be used to explore the potential for multiple bioretention practices versus relying on a single bioretention practice. Bioretention is best employed close to the source of runoff generation and is often located in the upstream portion of the stormwater treatment train, with additional stormwater BMPs following downstream.

Determine site infiltration rates (for facilities with infiltration and/or recharge)

For design purposes, there are two ways of determining the soil infiltration rate. The first, and preferred method, is to field-test the soil infiltration rate using appropriate methods described below. The other method uses the typical infiltration rate of the most restrictive underlying soil (determined during soil borings).

If infiltration rate measurements are made, a minimum of one infiltration test in a soil pit must be completed at the elevation from which exfiltration would occur (i.e. interface of gravel drainage layer and in situ soil). When the SCM surface area is between 1000

and 5000 square feet, two soil pit measurements are needed. Between 5000 and 10000 square feet of surface area, a total of three soil pit infiltration measurements should be made. Each additional 5000 square feet of surface area triggers an additional soil pit.

Recommended number of soil borings, pits or permeameter tests for bioretention design. Designers select one of these methods.

Link to this table

Surface area of stormwater control measure (BMP)(ft^2)	Borings	Pits	Permeameter tests
< 1000	1	1	5
1000 to 5000	2	2	10
5000 to 10000	3	3	15
>10000	4[1]	4[1]	20[2]

[1]an additional soil boring or pit should be completed for each additional 2,500 ft^2 above 12,500 ft^2

[2]an additional five permeameter tests should be completed for each additional 5,000 ft^2 above 15,000 ft^2

The median measured infiltration rate should be utilized for design. Soil pits should be dug during the design phase and should be a minimum of two feet in diameter for measurement of infiltration rate. Infiltration testing in the soil pit can be completed with a double-ring infiltrometer or by filling the pit with water and measuring stage versus time. If the infiltration rate in the first pit is greater than 2 inches per hour, no additional pits shall be needed.

Alternatively, a Modified Philip-Dunne permeameter can be used to field test infiltration rate. Modified Philip-Dunne permeameter tests may be made in conjunction with soil borings or may be completed using a handheld soil auger. Borings should be lined with a plastic sleeve to prevent infiltration from the sides of the borehole (i.e. restrict flow to vertical infiltration). Soil borings should be filled with water. The time for the borehole to drain should be recorded and divided by the initial ponding depth in the borehole to provide an infiltration rate measurement. The design infiltration rate should be the lower of the median soil pit infiltration rate or the median borehole method infiltration rate.

NOTE: In the table above, the recommended number of permeameter tests increases by 5 tests per each additional 5000 square feet of surface area. For larger sites, this can result in a very large number of samples. There may be situations where fewer

permeameter tests may be used (5 is the minimum) . For example, in situations where the variability in saturated hydraulic conductivity between measurements is not great, fewer samples may be taken. One method for determining the number of samples is to plot standard deviation versus number of samples. Measurements may be halted when the standard deviation becomes relatively constant from one sample to the next. In the example to the right the standard deviation flattens at about 7 to 10 samples. Therefore, 7 to 10 samples would be an appropriate number of samples for this situation.

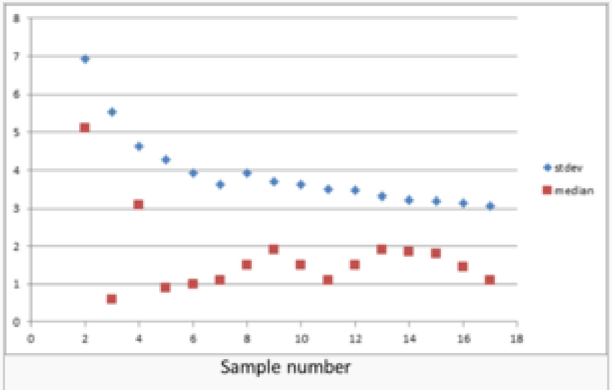


Illustration of how to determine the appropriate number of permeameter samples. The y-axis represents the standard deviation or median hydraulic conductivity. When the standard deviation for all measurements flattens out with successive measurements, collection of additional permeameter tests may be halted, provided a minimum of 5 samples have been collected.

For information on conducting soil infiltration rate measurements, see Determining soil infiltration rates.

If the infiltration rate is not measured, use the table below to estimate an infiltration rate for the design of infiltration practices. These infiltration rates represent the long-term infiltration capacity of a practice and are not meant to exhibit the capacity of the soils in the natural state.

Caution: Select the design infiltration rate from the table based on the least permeable soil horizon within the first 5 feet below the bottom elevation of the proposed infiltration practice

Caution: The table for design infiltration rates has been modified. Field testing is recommended for gravelly soils (HSG A; GW and GP soils; gravel and sandy gravel soils). If field-measured soil infiltration rates exceed 8.3 inches per hour, the Construction Stormwater permit requires the soils be amended. Guidance on amending these soils can be found here.

Design infiltration rates, in inches per hour, for A, B, C, and D soil groups. Corresponding USDA soil classification and Unified soil Classifications are included. Note that A and B soils have two infiltration rates that are a function of soil texture.*
The values shown in this table are for uncompacted soils. This table can be used as a guide to determine if a soil is compacted. For information on alleviating compacted soils, link here. If a soil is compacted, reduce

the soil infiltration rate by one level (e.g. for a compacted B(SM) use the infiltration rate for a B(MH) soil).
Link to this table

Hydrologic soil group	Infiltration rate (inches/hour)	Infiltration rate (centimeters/hour)	Soil textures	Corresponding Unified Soil Classification
A	Although a value of 1.63 inches per hour (4.14 centimeters per hour) may be used, it is ***Highly recommended*** that you conduct field infiltration tests or amend soils.[b] See Guidance for amending soils with rapid or high infiltration rates and Determining soil infiltration rates.		gravel sandy gravel	GW - well-graded gravels, sandy gravels GP - gap-graded or uniform gravels, sandy gravels
	1.63[a]	4.14	silty gravels gravelly sands sand	GM - silty gravels, silty sandy gravels SW - well-graded gravelly sands SW - uniformly graded sands
	0.8	2.03	sand loamy sand sandy loam	SP - gap-graded or poorly graded sands
B	0.45	1.14		SM - silty sands, silty gravelly sands

	0.3	0.76	loam, silt loam	MH - micaceous silts, diatomaceous silts, volcanic ash
C	0.2	0.51	Sandy clay loam	ML - silts, very fine sands, silty or clayey fine sands
D	0.06	0.15	clay loam silty clay loam sandy clay silty clay clay	GC - clayey gravels, clayey sandy gravels SC - clayey sands, clayey gravelly sands CL - low plasticity clays, sandy or silty clays OL - organic silts and clays of low plasticity CH - highly plastic clays and sandy clays OH - organic silts and clays of high plasticity

*NOTE that this table has been updated from Version 2.X of the Minnesota Stormwater Manual. The higher infiltration rate for B soils was decreased from 0.6 inches per hour to 0.45 inches per hour and a value of 0.06 is used for D soils (instead of < 0.2 in/hr).

Source: Thirty guidance manuals and many other stormwater references were reviewed to compile recommended infiltration rates. All of these sources use the following studies as the basis for their recommended infiltration rates: (1) Rawls, Brakensiek and Saxton (1982); (2) Rawls, Gimenez and Grossman (1998); (3) Bouwer and Rice (1984); and (4) Urban Hydrology for Small Watersheds (NRCS). SWWD, 2005, provides field documented data that supports the proposed infiltration rates. (view reference list)

[a]This rate is consistent with the infiltration rate provided for the lower end of the Hydrologic Soil Group A soils in the Wisconsin Department of Natural Resources Conservation Practice Standard: Site Evaluation for Stormwater Infiltration.

[b]The infiltration rates in this table are recommended values for sizing stormwater practices based on information collected from soil borings or pits. A group of technical experts developed the table for the original Minnesota Stormwater Manual in 2005. Additional technical review resulted in an update to the table in 2011. Over the past 5 to 7 years, several government agencies revised or developed guidance for designing infiltration practices. Several states now require or strongly recommend field infiltration tests. Examples include North Carolina, New York, Georgia, and the City of Philadelphia. The states of Washington and Maine strongly recommend field testing for infiltration rates, but both states allow grain size analyses in the determination of infiltration rates. The Minnesota Stormwater Manual strongly recommends field testing for infiltration rate, but allows information from soil borings or pits to be used in determining infiltration rate. A literature review suggests the values in the design infiltration rate table are not appropriate for soils with very high infiltration rates. This includes gravels, sandy gravels, and uniformly graded sands. Infiltration rates for these geologic materials are higher than indicated in the table.

References: Clapp, R. B., and George M. Hornberger. 1978. Empirical equations for some soil hydraulic properties. Water Resources Research. 14:4:601–604; Moynihan, K., and Vasconcelos, J. 2014. SWMM Modeling of a Rural Watershed in the Lower Coastal Plains of the United States. Journal of Water Management Modeling. C372; Rawls, W.J., D. Gimenez, and R. Grossman. 1998. Use of soil texture, bulk density and slope of the water retention curve to predict saturated hydraulic conductivity Transactions of the ASAE. VOL. 41(4): 983-988; Saxton, K.E., and W. J. Rawls. 2005. Soil Water Characteristic Estimates by Texture and Organic Matter for Hydrologic Solutions. Soil Science Society of America Journal. 70:5:1569-1578.

The infiltration capacity and existing hydrologic regime of natural basins are inherently different than constructed practices and may not meet MPCA Permit requirements for constructed practices. In the event that a natural depression is being proposed to be used as an infiltration system, the design engineer must demonstrate the following information:

- infiltration capacity of the system under existing conditions (inches per hour)
- existing drawdown time for the high water level (HWL) and a natural overflow elevation.

The design engineer should also demonstrate that operation of the natural depression under post-development conditions mimics the hydrology of the system under pre-development conditions.

If the infiltration rates are measured, the tests shall be conducted at the proposed bottom elevation of the infiltration practice. If the infiltration rate is measured with a double-ring infiltrometer the requirements of ASTM D3385 (Standard test method for infiltration

rate of soils in field using double-ring infiltrometer) should be used for the field test.

Warning: The measured infiltration rate shall be divided by a safety factor of 2.

The safety factor of 2 adjusts the measured infiltration rates for the occurrence of less permeable soil horizons below the surface and the potential variability in the subsurface soil horizons throughout the infiltration site. This safety factor also accounts for the long-term infiltration capacity of the stormwater management facility.

Size bioretention area

To meet requirements of the Stormwater General Permit (CSW permit), the surface area (A_s, in square feet) of a bioinfiltration practice is given by

$A_s = V_w / D_o$

Where:
V_w = the water treatment volume of the area contributing runoff to the practice; and
D_o = the storage depth of ponded water in the practice.

The water treatment volume is given by

$V_w = 0.0833 A_c$

Where
0.0833 = one inch of infiltration, as required by the permit; and
A_c = the impervious surface area contributing to the practice.

The entire water quality treatment volume is assumed to be instantaneously ponded in the bioinfiltration practice.

For a bioretention BMP with sloped sides, the surface area (A_s) of an infiltration practice is the average area of the BMP, given by

$A_s = (A_o + A_M)/2$

Where
A_o is the surface area at the overflow; and
A_M is the surface area at the top of the bioretention media

The water treatment volume must drain with 48 hours (24 hours is RECOMMENDED if discharges from the practice are to a trout stream). The ponding depth can therefore be calculated knowing the infiltration rate of the soils underlying the practice. Field-measured infiltration rates are preferred. If the infiltration rate has not been measured, use the table below to determine the infiltration rate of the underlying soils. The ponded depth must not exceed 18 inches (1.5 feet) regardless of the soil infiltration rate. Note the numbers in the table are intentionally conservative based on experience gained from Minnesota infiltration sites. Two example calculations are provided below.

Example 1 Assume a 5 acre watershed is 20 percent impervious. Runoff from this watershed will be routed to a bioinfiltration practice that has an underlying loam soil.

- The treatment volume = 5 acres * 0.20 * 43560 square feet per acre * 0.0833 inches = 3630 cubic feet
- The ponded depth = 48 hours * 0.30 inches per hour = 14.4 inches = 1.2 feet
- The surface area of the practice = 3025 square feet

The dimensions of the bioinfiltration practice can be determined to accommodate this area. For example, a square practice will be 55 feet wide by 55 feet long. Note that the depth of 1.2 feet meets the requirement that the ponded depth be 1.5 feet or less.

Example 2 Assume a 7 acre watershed is 15 percent impervious. Runoff from this watershed will be routed to a bioinfiltration practice where the underlying soil has a field-measured infiltration rate of 2 inches per hour.

Note:

- The watershed acreage exceeds the RECOMMENDED 5 acre maximum size.
- The infiltration rate must be divided by a safety factor of 2 since a field-measure rate is being used. This gives an infiltration rate of 1 inch per hour.
- The ponded depth = 48 hours * 1 inch per hour = 48 inches = 4 feet. This exceeds the maximum depth of 1.5 feet. Thus the ponded depth is set equal to 1.5 feet.
- The treatment volume = 7 acres * 0.15 * 43560 square feet per acre * 0.0833 inches = 3811 cubic feet
- The surface area of the practice = $3811 ft^3$ / 1.5ft = 2541 square feet

The dimensions of the bioinfiltration practice can be determined to accommodate this volume. For example, a square practice will be 50.4 feet wide by 50.4 feet long.

If the bioinfiltration practice does not require meeting the Construction Stormwater General Permit, methods other than the instantaneous volume method may be used. For example, as a bioinfiltration basin fills during a rain event, water infiltrates the media. The bioinfiltration area could be sized as follows

$A_s = V_{wq} / (D_o + (I_R * t))$

Where:
I_R = infiltration rate of underlying soils (feet per day);and
t = time during which the bioretention basin continues to capture runoff.

The time during which runoff continues to be delivered to the BMP varies with each event. As an example, for a 1 hour event on a B (SM) soil with an infiltration rate of 0.45 inches per hour, 1 acre of contributing impervious area, and a 1.5 foot ponding depth, A_s is 2361 square feet, compared to 2420 square feet considering only an instantaneous volume, or a decrease of 2.4 percent in the size of the basin. On an A soil with and infiltration rate of 1.6 inches per hour, A_s is 2222 square feet, or a decrease of 8.2 percent in the needed size of the basin. The area of the basin can also be decreased by increasing the ponded depth to greater than the 1.5 foot recommended. However, increased ponding depths increase the inundation time for plants in the bioretention basin.

Bioinfiltration practices may also be sized using different treatment goals. For example, the performance goal for Minimal Impact Design Standards (MIDS) is 1.1 inches, compared to 1 inch for the CSW permit. The MIDS performance goal was also based on initial modeling that included infiltration during the rain event.

Warning: 48 hours is the *REQUIRED* maximum t_f for bioretention under the CGP

Caution: The table for design infiltration rates has been modified. Field testing is recommended for gravelly soils (HSG A; GW and GP soils; gravel and sandy gravel soils). If field-measured soil infiltration rates exceed 8.3 inches per hour, the Construction Stormwater permit requires the soils be amended. Guidance on amending these soils can be found here.

Design infiltration rates, in inches per hour, for A, B, C, and D soil groups. Corresponding USDA soil classification and Unified soil Classifications are included. Note that A and B soils have two infiltration rates that are a function of soil texture.*
The values shown in this table are for uncompacted soils. This table can be used as a guide to determine if a soil is compacted. For information on alleviating compacted soils, link here. If a soil is compacted, reduce the soil infiltration rate by one level (e.g. for a compacted B(SM) use the infiltration rate for a B(MH) soil).

Link to this table

Hydrologic soil group	Infiltration rate (inches/hour)	Infiltration rate (centimeters/hour)	Soil textures	Corresponding Unified Soil Classification
A	Although a value of 1.63 inches per hour (4.14 centimeters per hour) may be used, it is ***Highly recommended*** that you conduct field infiltration tests or amend soils.[b] See Guidance for amending soils with rapid or high infiltration rates and Determining soil infiltration rates.		gravel sandy gravel	GW - well-graded gravels, sandy gravels GP - gap-graded or uniform gravels, sandy gravels
	1.63[a]	4.14	silty gravels gravelly sands sand	GM - silty gravels, silty sandy gravels SW - well-graded gravelly sands SW - uniformly graded sands
	0.8	2.03	sand loamy sand	SP - gap-graded or poorly graded sands

			sandy loam	
B	0.45	1.14		SM - silty sands, silty gravelly sands
	0.3	0.76	loam, silt loam	MH - micaceous silts, diatomaceous silts, volcanic ash
C	0.2	0.51	Sandy clay loam	ML - silts, very fine sands, silty or clayey fine sands
D	0.06	0.15	clay loam silty clay loam sandy clay silty clay clay	GC - clayey gravels, clayey sandy gravels SC - clayey sands, clayey gravelly sands CL - low plasticity clays, sandy or silty clays OL - organic silts and clays of low plasticity CH - highly plastic clays and sandy clays OH - organic

				silts and clays of high plasticity

*NOTE that this table has been updated from Version 2.X of the Minnesota Stormwater Manual. The higher infiltration rate for B soils was decreased from 0.6 inches per hour to 0.45 inches per hour and a value of 0.06 is used for D soils (instead of < 0.2 in/hr).

Source: Thirty guidance manuals and many other stormwater references were reviewed to compile recommended infiltration rates. All of these sources use the following studies as the basis for their recommended infiltration rates: (1) Rawls, Brakensiek and Saxton (1982); (2) Rawls, Gimenez and Grossman (1998); (3) Bouwer and Rice (1984); and (4) Urban Hydrology for Small Watersheds (NRCS). SWWD, 2005, provides field documented data that supports the proposed infiltration rates. (view reference list)

[a]This rate is consistent with the infiltration rate provided for the lower end of the Hydrologic Soil Group A soils in the Wisconsin Department of Natural Resources Conservation Practice Standard: Site Evaluation for Stormwater Infiltration.

[b]The infiltration rates in this table are recommended values for sizing stormwater practices based on information collected from soil borings or pits. A group of technical experts developed the table for the original Minnesota Stormwater Manual in 2005. Additional technical review resulted in an update to the table in 2011. Over the past 5 to 7 years, several government agencies revised or developed guidance for designing infiltration practices. Several states now require or strongly recommend field infiltration tests. Examples include North Carolina, New York, Georgia, and the City of Philadelphia. The states of Washington and Maine strongly recommend field testing for infiltration rates, but both states allow grain size analyses in the determination of infiltration rates. The Minnesota Stormwater Manual strongly recommends field testing for infiltration rate, but allows information from soil borings or pits to be used in determining infiltration rate. A literature review suggests the values in the design infiltration rate table are not appropriate for soils with very high infiltration rates. This includes gravels, sandy gravels, and uniformly graded sands. Infiltration rates for these geologic materials are higher than indicated in the table.

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All bioretention growing media should have a field tested infiltration rate between 1 and 8 inches per hour. Growing media with slower infiltration rates could clog over time and may not meet drawdown requirements. Target infiltration rates should be no more than 8 inches per hour to allow for adequate water retention for vegetation as well as adequate retention time for pollutant removal. Slower rates (2 inches per hour or less) are recommended if the primary pollutant(s) of concern are temperature, total nitrogen or total phosphorus. If the infiltration rate of the growing media has not been field tested, the coefficients of permeability

recommended for the Planting Medium / Filter Media Soil is 0.5 feet per day (Claytor and Schueler, 1996). Note: the value is conservative to account for clogging associated with accumulated sediment.

Step 6. Size outlet structure and/or flow diversion structure, if needed

(Note: Steps 5, 6, 7 and 8 are iterative)

Warning: It is *REQUIRED* that an outlet be incorporated into the design of a bioretention practice to safely convey excess stormwater.

Step 7. Perform groundwater mounding analysis

(Note: Steps 5, 6, 7 and 8 are iterative) Groundwater mounding, the process by which a mound forms on the water table as a result of recharge at the surface, can be a limiting factor in the design and performance of bioretention practices where infiltration is a major design component. A minimum of 3 feet of separation between the bottom of the bioretention practice and seasonally saturated soils (or from the top of bedrock) is *REQUIRED* (5 feet *RECOMMENDED*) to maintain the hydraulic capacity of the practice and provide adequate water quality treatment. A groundwater mounding analysis is *RECOMMENDED* to verify this separation for infiltration designed bioretention practices.

The most widely known and accepted analytical methods to solve for groundwater mounding is based on the work by Hantush (1967) and Glover (1960). The maximum groundwater mounding potential should be determined through the use of available analytical and numerical methods. Detailed groundwater mounding analysis should be conducted by a trained hydrogeologist or equivalent as part of the site design procedure.

Step 8. Determine pre-treatment volume and design pre-treatment measures

Warning: Some form of dry or wet pre-treatment is *REQUIRED* prior to the discharge of stormwater into the bioretention practice, to remove any sediment and fines that may result in clogging of the soils in the sediment basin area.

If a grass filter strip is used, it is *HIGHLY RECOMMENDED* that it be sized using the guidelines in the table below.

Guidelines for filter strip pre-treatment sizing

Link to this table

Parameter	Impervious Parking Lots				Residential Lawns			
Maximum Inflow Approach Length (ft)	35		75		75		150	
Filter Strip Slope	=<2%	>2%	=<2%	2%	=<2%	2%	=<2%	2%
Filter Strip Minimum Length	10'	15'	20'	25'	10'	12'	15'	18'

Grass channel sizing

It is *HIGHLY RECOMMENDED* that grass channel pre-treatment for bioretention be a minimum of 20 feet in length and be designed according to the following guidelines:

- parabolic or trapezoidal cross-section with bottom widths between 2 and 8 feet;
- channel side slopes no steeper than 3:1 (horizontal:vertical);
- flow velocities limited to 1 foot per second or less for peak flow associated with the water quality event storm (i.e., 0.5 or 1.0 inches depending on watershed designation); and
- flow depth of 4 inches or less for peak flow associated with the water quality event storm.

Step 9. Check volume, peak discharge rates and period of inundation against State, local and watershed management organization requirements

(Note: Steps 5, 6, 7 and 8 are iterative)

Follow the design procedures identified in the Unified sizing criteria section to determine the volume control and peak discharge recommendations for water quality, recharge, channel protection, overbank flood and extreme storm.

Model the proposed development scenario using a surface water model appropriate for the hydrologic and hydraulic design considerations specific to the site (see also Introduction to stormwater modeling). This includes defining the parameters of the bioretention practice defined above: sedimentation basin elevation and area (defines the pond volume), infiltration/permeability rate, and outlet structure and/or flow diversion information. The results of this analysis can be used to determine whether or not the proposed design meets the applicable requirements. If not, the design will have to be re-evaluated (back to Step 5).

The following items are specifically REQUIRED by the MPCA Permit:

Warning:

- *Volume* - Infiltration or filtration systems shall be sufficient to infiltrate or filter a water quality volume of 1 inch of runoff from the new impervious surfaces created by the project. If this criterion is not met, increase the storage volume of the bioretention practice or treat excess water quality volume (Vwq) in an upstream or downstream BMP (see Step 5). Retrofit and supplemental systems do not need to meet this requirement, provided new impervious surfaces are not created.
- *Peak Discharge Rates* - Since most bioretention systems are not designed for quantity control they generally do not have peak discharge limits. However outflow must be limited such that erosion does not occur down gradient.
- *Drawdown period* - Bioretention practices shall discharge through the soil or filter media in 48 hours or less. Additional flows that cannot be infiltrated or filtered in 48 hours should be routed to bypass the system through a stabilized discharge point.

Experience has demonstrated that, although the drawdown period is 48 hours, there is often some residual water pooled in the infiltration practice after 48 hours. This residual water may be associated with reduced head, water gathered in depressions within the practice, water trapped by vegetation, and so on. The drawdown period is therefore defined as the time from the high water level in the practice to 1 to 2 inches above the bottom of the facility. This criterion was established to provide the following: wet-dry cycling between rainfall events; unsuitable mosquito breeding habitat; suitable habitat for vegetation; aerobic conditions; and storage for back-to-back precipitation events. This time period has also been called the period of inundation.

Other design requirements may apply to a particular site. The applicant should confirm local design criteria and applicability (see Step 2).

Step 10. Prepare vegetation and landscaping plan

See Major Design Elements for guidance on preparing vegetation and landscaping management plan.

Step 11. Prepare operations and maintenance (O&M) plan

See Operations and Maintenance for guidance on preparing an O&M plan.

Step 12. Prepare cost estimate

See Cost Considerations section for guidance on preparing a cost estimate that includes both construction and maintenance costs.

Construction specifications for bioretention

This page provides construction details, materials specifications and construction specifications for bioretention systems.

Information on this page has recently been added or updated. Acknowledgements.

Construction details

CADD based details for bioretention are contained in the Computer-aided design and drafting (CAD/CADD) drawings section. The following details, with specifications, have been created for bioretention systems:

- Bioretention Facilities General Plan
  - Bioretention plan-offline **NEW**
  - Bioretention plan-online **NEW**
  - Biofiltration planter - Plan **NEW**
  - Bioretention parking median - Plan **NEW**

- Bioretention Facilities Performance Types Cross-Sections
  - Bioinfiltration **NEW**
  - Biofiltration with underdrain at the bottom **NEW**
  - Biofiltration with elevated underdrain **NEW**
  - Biofiltration with internal water storage **NEW**
  - Biofiltration with liner **NEW**
  - Biofiltration planter - Section **NEW**
  - Bioretention parking median - Section **NEW**
  - Cleanout **NEW**
  - Underdrain valve **NEW**
  - Biofiltration with elevated underdrain **NEW**
  - Biofiltration with internal water storage **NEW**
  - Biofiltration with underdrain at bottom **NEW**
  - Bioinfiltration **NEW**
  - Biofiltration with liner **NEW**
  - Infiltration / Recharge Facility
  - Filtration / Partial Recharge Facility
  - Infiltration / Filtration / Recharge Facility
  - Filtration Only Facility

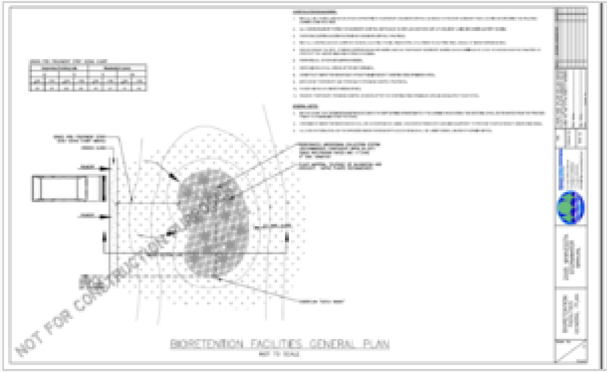


Illustration of a cross-section for a bioretention facilities general plan. To access plans and .dwg files, click here.

Information: Information on bioretention media mixes, previously included on this page, has been moved to the section on design criteria.

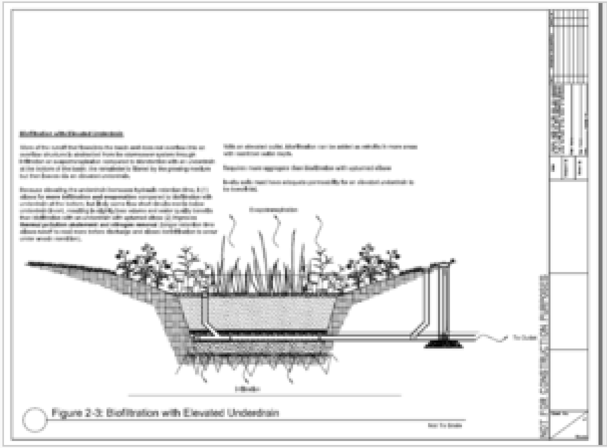


Illustration of a cross-section of a bioretention BMP with an elevated underdrain. To access cross-sections and .dwg files, click here.

Construction specifications

Information: Off-line construction is preferred to allow for establishment of vegetation

Proper construction techniques are critical to achieve long-term functionality of bioretention systems. Construction sequencing is imperative; infiltration BMPs need to be installed as close to the end of construction as possible. Preferably, site slopes have been stabilized and the asphalt has been installed before the bioretention construction begins. However, this is not always possible in bioretention cells that are surrounded by a parking lot and are the only outlet for stormwater. In this case, excavate the bioretention cell during a period of dry weather. Install the underdrains, the outlet structure, and the media up to the proposed final elevation. Once the construction of the parking lot is complete, scrape off any silty or clayey confining layer that has accumulated on top of the media and remove it from the site and de-compact soil. Top up media to desired finished elevation. Mulch and plants (or sod if it is a grassed bioretention cell) may then be installed.

During construction it is critical to keep sediment out of the infiltration device as much as practicable. Utilizing sediment and erosion control measures, such as compost logs, check dams, and sediment basins, will help to keep bioretention cells from clogging. As soon as grading is complete, slopes should be stabilized to reduce erosion of native soils. If vegetated filter strips are used as pre-treatment, they must be vegetated as soon as possible following the completion of grading.

If the bioretention cell has sod specified for its cover (as opposed to tree/shrub/mulch systems), the sod must be either 1) grown on sandy underlying soils or 2) be washed sod. Washed sod has had all soil removed from the roots, which prevents the sod layer from restricting infiltration into the underlying media. It also typically roots more quickly than standard sod.

Preventing and alleviating compaction are crucial during construction of infiltration practices, as compaction can reduce infiltration rates in sandy soils by an order of magnitude and in clayey soils by a factor of 50 (Pitt et al. , 2008). Therefore, it is critical to keep heavy construction equipment from compacting or smearing soils at the bottom of the excavation. Excavate the soil from the perimeter of the infiltration device. Tracked vehicles should be used to reduce the pressure placed on the soil. It is highly recommended to excavate during dry conditions to prevent smearing of the soil, which has been shown to reduce the soil infiltration rate (Brown and Hunt, 2010). Driveable mats can be used for backfill and grading to minimize compaction. During the final pass with the excavator bucket (i.e. bottom of excavation), it is highly recommended to rake the soil with the teeth of the bucket to loosen any compaction (Brown and Hunt, 2010). Smooth bucket blades smear soils and restrict infiltration rates. Soil ripping has also been shown to increase infiltration and reduce compaction from construction activities (Tyner et al., 2009; Wardynski et al., 2013).

Given that the construction of bioretention practices incorporates techniques or steps which may be considered non-traditional, it is recommended that the construction specifications include the format and information discussed below.

Temporary erosion control

Warning:

- It is REQUIRED that future bioretention locations not be used as temporary sedimentation basins unless 3 feet of cover is left in place during construction.
- If the bioretention area is excavated to final grade (or within 3 feet of) it is REQUIRED that rigorous erosion prevention and sediment controls (e.g. diversion berms) are used to keep sediment and runoff completetly away from the bioretention area.

Demonstration of the rake technique with a bucket with teeth (top) and scoop technique using a bucket with a smooth blade (right). During the final pass of excavation, the rake technique should be used to break up the soil and promote exfiltration. Source: Dr. Robert Brown, ORISE Research Fellow, US EPA, Edison, NJ.

- Install prior to site disturbance
- Protect catch basin/inlet
- Cover erodible surfaces, for example with plastic covers, that can be re-used.

Excavation, backfill and grading

- It is HIGHLY RECOMMENDED that prior to beginning the installation, sufficient material quantities shall be onsite to complete the installation and stabilize exposed soil areas without delay.
- It is HIGHLY RECOMMENDED that excavation, soil placement and rapid stabilization of perimeter slopes be completed before the next precipitation event
- Timing of grading of infiltration practices relative to total site development
- Use of low-impact, earth moving equipment (wide track or marsh track equipment, or light equipment with turf-type tires)
- Do not over-excavate
- Restoration in the event of sediment accumulation during construction of practice
- Alleviate any compacted soil (compaction can be alleviated at the base of the practice by using a primary tilling operation such as a chisel plow, ripper or sub-soiler to a minimum 12 inch depth
- Gravel backfill specifications

- Gravel filter specifications
- Filter fabric specifications

Alleviating compaction resulting from construction

Alleviation of compaction of disturbed soil is crucial to the installation of successful vegetated stormwater infiltration practices. Typical bulk densities for non-compacted soils are in the range of 1.0 to 1.50 grams per cubic centimeter. Urban soils typically have bulk densities greater than this. Construction activities can increase bulk densities by 20 percent or more. The compaction can extend up to two feet into the soil profile, often resulting in bulk densities that do not readily support healthy plant growth.

Comparison of bulk densities for undisturbed soils and common urban conditions

Link to this table

Undisturbed soil type or urban condition	Surface bulk density (grams / cubic centimeter
Peat	0.2 to 0.3
Compost	1.0
Sandy soil	1.1 to 1.3
Silty sands	1.4
Silt	1.3 to 1.4
Silt loams	1.2 to 1.5
Organic silts / clays	1.0 to 1.2
Glacial till	1.6 to 2.0
Urban lawns	1.5 to 1.9
Crushed rock parking lot	1.5 to 2.0
Urban fill soils	1.8 to 2.0
Athletic fields	1.8 to 2.0
Rights of way and building pads (85% compaction)	1.5 to 1.8

Rights of way and building pads (95% compaction)	1.6 to 2.1
Concrete pavement	2.2
Quartzie (rock)	2.65

Increase in soil bulk density as a result of different land uses or activities.

Link to this table

Land use or activity	Increase in bulk density (grams / cubic centimeter	Source (link to Reference list)
Grazing	0.12 to 0.20	Smith, 1999
Crops	0.25 to 0.35	Smith, 1999
Construction, mass grading	0.34 to 0.35	Randrup, 1998; Lichter and Lindsey, 1994
Construction, no grading	0.20	Lichter and Lindsey, 1994
Construction traffic	0.17 to 0.40	Lichter and Lindsey, 1994; Smith, 1999; Friedman, 1998
Athletic fields	0.38 to 0.54	Smith, 1999
Urban lawn and turf	0.30 to 0.40	Various sources

While natural processes can alleviate soil compaction, additional techniques to alleviate soil compaction are often desirable because

- it can take many years for natural processes to loosen up soil;
- natural processes operate primarily within the first foot or so of soil, and compaction from development can extend to two feet deep; and
- once soil compaction becomes so severe that plants and soil microbes can no longer thrive, natural processes are no longer able to reduce soil compaction.

The most effective method for alleviating compaction is to add compost amendment. Other amendments, such as sand (in clay soils), can significantly reduce compaction since sandy soils are more resistant to compaction. An additional technique for alleviating compaction is subsoiling or soil ripping, although ripping by itself appears to have limitations. Ripping is most effective when used in conjunction with compost and/or sand amendment.

Schueler (Technical Note 108) concludes that “Based on current research, it appears that the best construction techniques are only capable of preventing about a third of the expected increase in bulk density during construction.”

Reported activities that restore or decrease soil bulk density

Link to this table

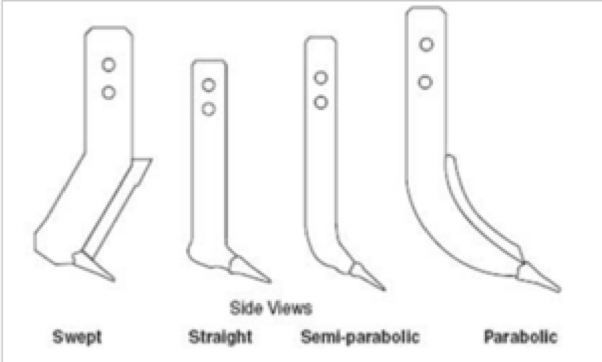
Land use or activity	Decrease in bulk density (grams / cubic centimeter	Source (link to Reference list)
Tilling of soil	0.00 to 0.02	Randrup, 1989; Patterson and Bates, 1994
Specialized soil loosening	0.05 to 0.15	Rolf, 1998
Selective grading	0.00	Randrup, 1998; Lichter and Lindsey, 1994
Soil amendments	0.17	Patterson and Bates, 1994
Compost amendment	0.25 to 0.35	Kolsti et al., 1995
Time	0.20	Legg et al., 1996
Reforestation	0.25 to 0.35	Article 36

Soil ripping

The goal of soil ripping or subsoiling is to fracture compacted soil without adversely disturbing plant life, topsoil, and surface residue. Soil compaction occurs most frequently with soils having a high clay content. Fracturing compacted soil promotes root penetration by reducing soil density and strength, improving moisture infiltration and retention, and increasing air spaces in the soil. Compacted layers typically develop 12 to 22 inches below the surface when heavy equipment is used. Conventional cultivators cannot reach deep enough to break up this compaction. Subsoilers (rippers) can break up the compacted layer without destroying soil aggregate structure, surface vegetation, or mixing soil layers (Kees, 2008).

How effectively compacted layers are fractured depends on the soil's moisture, structure, texture, type, composition, porosity, density, and clay content. Success depends on the type of equipment selected, its configuration, and the speed with which it is pulled through the ground. No one piece of equipment or configuration works best for all situations and soil conditions, making it difficult to define exact specifications for subsoiling equipment and operation.

Subsoilers are available with a wide variety of shank designs. Shank design affects subsoiler performance, shank strength, surface and residue disturbance, effectiveness in fracturing soil, and the horsepower required to pull the subsoiler. According to Kees (2008), “Parabolic shanks require the least amount of horsepower to pull. In some forest applications, parabolic shanks may lift too many stumps and rocks, disturb surface materials, or expose excess subsoil. Swept shanks tend to push materials into the soil and sever them. They may help keep the subsoiler from plugging up, especially in brush, stumps, and slash. Straight or "L" shaped shanks have characteristics that fall somewhere between those of the parabolic and swept shanks.”

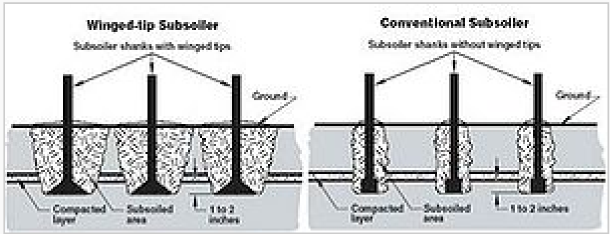


Example of different shank designs commonly used for agricultural tillage (Kees, 2008).

Photos of wing tip and conventional tip subsoilers (Kees, 2008).

Researchers have found that there is a “critical depth”, and according to Spoor and Godwin (1978) this “critical depth is dependent upon the width, inclination and lift height of the tine foot and on the moisture and density status of the soil.” Spoor and Godwin (1978) explainthat tine depth is crucial because “At shallow working depths the soil is displaced forwards, side-ways and upwards (crescent failure), failing along well defined rupture planes which radiate from just above the tine tip to the surface at angles of approximately 45” to the horizontal. Crescent failure continues with increasing working depth until, at a certain depth, the critical depth, the soil at the tine base begins to flow forwards and sideways only (lateral failure) creating compaction at depth.” They found that below the critical depth “compaction occurs rather than effective soil loosening.” They also found that “The wetter and more plastic a soil is, the shallower is thecritical depth.” An approach developed by Silsoe College, Cranfield University, in collaboration with Transco UK, for use on pipeline sites, was to work progressively deeper with repeated passes, up to 5 or 6 under extreme conditions, with the tractor operating on the same tramline/traffic lane on each pass (Spoor & Foot, 1998).”

Shanks are available with winged tips and conventional tips. Winged tips cost more than conventional tips and require more horsepower, but can often be spaced farther apart. Increasing wing width also increases critical depth – the depth below which little soil loosening occurs (Owen 1987, Spoor 1978). Using shallow leading tines ahead of deeper tines also increases required shank spacing (Spoor 1978). According to Kees (2008), the shank’s tip should run to a depth of 1 to 2 inches below the compacted layer. Kees (2008) also recommends making sure that the shanks on the subsoiler are spaced so that they run in the tracks of the tow vehicle, because the equipment used to pull subsoilers is heavy enough to create compaction itself. Ideal shank spacing will depend on soil moisture, soil type,degree of compaction, and the depth of the compacted layer. Spacing should be adjustable so the worked area can be fractured most efficiently. Because ideal shank configuration will vary with varying soil textures and moisture, shank spacing and height should be adjustable in the field (Kees 2008).

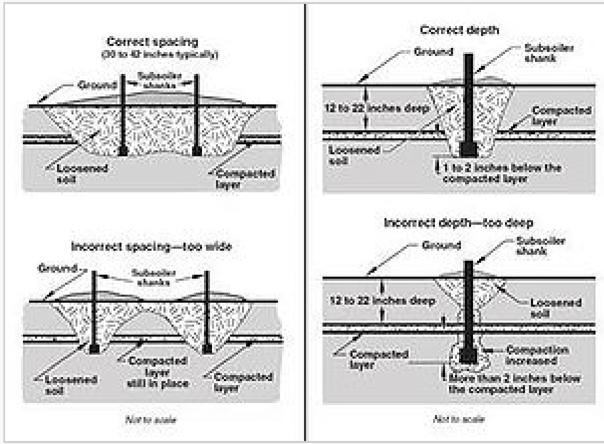


Comparison of soil disturbance from a winged tip versus a conventional tip: winged tips can typically be spaced farther apart because they fracture more of the soil than conventional tips (Kees, 2008).

Kees (2008) recommends following ground contours whenever possible when subsoiling to “increase water capture, protect water quality, and reduce soil erosion.” He also states that “in some cases, two passes at an angle to each other may be required to completely fracture compacted soil.” Spoor and Godwin (1978) also found that “Relatively closely spaced tines, staggered to prevent blockage, are more efficient at producing complete loosening than repeated passes with tines at wider spacings.”

Travel speed of the subsoiler also affects subsoiling disturbance. “Travel speed that is too high can cause excessive surface disturbance, bring subsoil materials to the surface, create furrows, and bury surface residues. Travel speed that is too slow may not lift and fracture the soil adequately” (Kees2008).

Soils should be mostly dry and friable. Urban (2008) describes ideal conditions for compaction reduction as follows: “soil moisture must be between field capacity and wilt point during compaction reduction for maximum effectiveness."



Impacts of having subsoiler shanks spaced correctly (top left) versus spaced too widely apart (bottom left) and having shanks at correct depth (top right) versus too deep (bottom right) (Image from Kees, 2008). Note: compaction on a construction site can be much more

Always know where utilities are buried prior to subsoiling. Avoid subsoiling in area that have buried utilities, wires, pipes, culverts, or diversion channels (Kees 2008, Urban 2008).

severe than just the plow layer shown in the above agricultural or forestry images.

Soil ripping will generally be more effective with the addition of an amendment. This can be either sand or compost. Tilling in compost amendment may not be desirable on sites with steep slopes, a high water table, wet saturated soils, or downhill slope toward a house foundation (Schueler Technical Note #108) or where there are tree roots or utilities, or where nutrients leaching from compost would pose a problem. Since soil restoration techniques will need to be tailored to site conditions, a prescriptive soil restoration specification is not recommended. However, Pennsylvania, Virginia, and Washington State have specifications for soil amendment and restoration and these may be used as guidance in determining how to amend a compacted soil.

According to Spoor and Godwin (1978) "The number of variables involved and soil variation make the accurate prediction of the critical depth for field conditions impractical. Simple field modifications are available, however, such as increasing tine foot width and lift height or loosening the surface layers, to allow rapid implement adjustment to satisfy a range of field conditions."

If subsoiling was effective, "The ground should be lifted slightly and remain relatively even behind the subsoiler, without major disruption of surface residues and plants. No more than a little subsoil and a few rocks should be pulled to the surface. If large furrows form behind the subsoiler, the shanks may not be deep enough, the angle on winged tips may be too aggressive, or the travel speed may be too high" (Kees 2008).

Cost for subsoiling varies by project. The Pennsylvania Stormwater Best Management Practices Manual estimates the cost of tilling soils ranges from $800 to $1000 per acre, while the cost of compost amending soil is about the same.

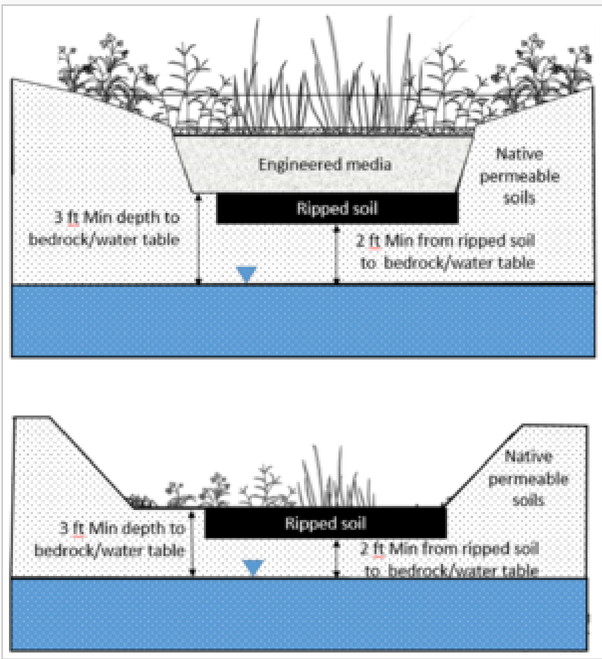
An extensive literature review of the effects of soil ripping can be found in File:Bioretention task 6 soil ripping.docx.

Recommendations for soil ripping to alleviate compaction

For basins larger than 1000 square feet, if compaction is above ideal bulk density indicated in the table below the soil should be remediated as follows:

- Rip to a depth of 18 inches where feasible
- For clay subsoil, incorporate 2 inches of sand. For bioretention without an underdrain, MnDOT Type 2 compost may be incorporated instead of sand.
- Maintain a 3 foot minimum separation distance between the bottom of the infiltration practice and the seasonally high water table or bedrock. If soil ripping is utilized, the requirement is a 2 foot minimum between the bottom of the ripped zone and a 3

foot minimum from the bottom of the infiltration practice to the water table or top of bedrock. If there is only a 3 foot separation distance between the bottom of the infiltration practice and the elevation of the seasonally high water table or bedrock, limit ripping depth to 1 foot (12 inches).



Schematic illustrating separation distance from bottom of infiltration BMP and soil ripped zones to water table or top of bedrock

General relationship of soil bulk density to root growth based on soil texture

Link to this table

Soil texture	Ideal bulk densities (g/cm^3)	Bulk densities that may affect plantgrowth (g/cm^3)	Bulk densities that restrict root growth (g/cm^3)
sands, loamy sands	<1.60	1.69	>1.80
sandy loams, loams	<1.40	1.63	>1.80
sandy clay loams, loams, clay loams	<1.40	1.60	>1.75
silts, silt loams	<1.30	1.60	>1.75
silt loams, silty clay loams	<1.40	1.55	>1.65
sandy clays, silty clays, clay loams with 35-45% clay	<1.10	1.49	>1.58
clays (>45% clay)	<1.10	1.39	>1.47

Effect of ripping plus compost amendment on soil compaction

Compost aggregates soil particles (sand, silt, and clay) into larger particles (Cogger, 2005). Aggregation of soil particles creates additional porosity, which reduces the bulk density of the soil (Cogger, 2005). Compost can also reduce the bulk density of a soil by dilution of the mineral matter in the soil (Cogger, 2005). When the porosity of the soil increases and the particle surface area increases, water holding capacity is also increased (Cogger, 2005). Increases in macropore continuity have been found as well (Harrison et al., 1998). Studies have cited numerous beneficial abilities of compost: increased water drainage, increased water holding capacity, increased plant production, increased root penetrability, reduction of soil diseases, reduction of heavy metals, and the ability to treat many chemical pollutants (EPA, 1997; Harrison et al., 1998; WDOE Stormwater Management Manual, 2007; Olson 2010).

Studies show that tilling in compost is an effective technique to alleviate soil compaction. Two of these studies are summarized below.

- Olson (2010) found that plots where soil was ripped and amended with compost showed reduced soil strength, bulk densities were 18 to 37 percent lower on compost plots compared to controls, and the geometric mean of K_{sat} on the compost plots was 2.7 to 5.7 times that of the control plot.
- A study at Virginia Tech shows soils with compost incorporated into the soil to a depth of 2 feet has decreased bulk density in the subsoil and is accelerating the process of soil formation and long-term carbon storage compared to other treatments in the study. The result is that trees growing in the compost-amended soil have increased height, canopy diameter, and trunk diameter compred to trees in other treatments.

Precedents for soil restoration specifications

Since soil restoration techniques will need to be tailored to site conditions, a prescriptive soil restoration specification is not recommended. The 2006 Pennsylvania Stormwater Best Management Practices Manual's chapter on soil amendment and restoration provides a sample specification for soil restoration. Their specification is not prescriptive, but does provide guiding principles, compost material specifications, and performance requirements. They require sub-soiling to loosen soil to less than 1400 kPa (200 psi) to a depth of 20 inches below final topsoil grade to reduce soil compaction in all areas where plant establishment is planned in areas where subsoil has become compacted by equipment operation, or has become dried out andcrusted, or where necessary to obliterate erosion hills.

The Virginia Tech Rehabilitation study website also provides a Soil Profile Rebuilding Specification based on their research. The basic steps in their specification are described below.

- Spread mature, stable compost to a 4 inch depth over compacted subsoil.
- Subsoil to a depth of 24 inches.

- Replace topsoil to 4 inches (6 to 8 inches if severely disturbed).
- Rototill topsoil to a depth of 6 to 8 inches.
- Plant with woody plants.

Washington State's Department of Ecology's Stormwater Management for Western Washington (Volume V: Runoff Treatment BMPs, Chapter 5, pages 5-7 to 5-10) also includes a very detailed soil restoration specification that includes the following.

- The topsoil layer has a minimum organic matter content of 10 percent dry weight in planting beds, 5 percent organic matter content in turf areas, and a pH from 6.0 to 8.0 or matching the pH of the undisturbed soil. The topsoil layer shall have a minimum depth of 8 inches except where tree roots limit the depth of incorporation of amendments needed to meet the criteria. Subsoils below the topsoil layer should be scarified at least 4 inches with some incorporation of the upper material to avoid stratified layers, where feasible.
- Mulch planting beds with 2 inches of organic material.
- Use compost and other materials that meet these organic content requirements.
    - The organic content for pre-approved amendment rates can be met only using compost that meets the definition of composted materials in WAC 173-350-100. The compost must also have an organic matter content of 40 to 65 percent and a carbon to nitrogen ratio below 25:1. The carbon to nitrogen ratio may be as high as 35:1 for plantings composed entirely of plants native to the Puget Sound Lowlands region.
    - Calculated amendment rates may be met through use of composted materials meeting above conditions, or other organic materials amended to meet the carbon to nitrogen ratio requirements and meeting the contaminant standards of Grade A Compost. The resulting soil should be conducive to the type of vegetation to be established.
- The soil quality design guidelines listed above can be met by using one of the methods listed below.
    - Leave undisturbed native vegetation and soil, and protect from compaction during construction.
    - Amend existing site topsoil or subsoil either at default pre-approved rates, or at custom calculated rates based on tests of the soil and amendment.
    - Stockpile existing topsoil during grading, and replace it prior to planting. Stockpiled topsoil must also be amended if needed to meet the organic matter or depth requirements, either at a default pre-approved rate or at a custom calculated rate.
    - Import topsoil mix of sufficient organic content and depth to meet the requirements. More than one method may be used on different portions of the same site. Soil that already meets the depth and organic matter quality standards, and is not compacted, does not need to be amended.

For a general guide that can be used in plant selection, see Plants for stormwater design by Shaw and Schmidt (2003).

Vigorous plants are crucial to the bioretention system's long term stormwater performance. Plant roots help soil particles form stable aggregates, improve soil structure, maintain and increase water storage and infiltration capacity, as well as improve stormwater pollutant removal. Specific stormwater benefits include the following.

- **Crucial to Long Term Infiltration**: As plant roots grow and then decay, they restore and/or enhance soil porosity and infiltration rates. Deeper rooted plants yield higher infiltration rates than shallow rooted plants. Bioretention practices with native prairie plants will typically have greater infiltration rates, deeper rooting depths, greater biological activity of flora and fauna, and deeper drainage compared to turf systems.
- **Crucial to Water Quality Benefits**: Plants in bioretention systems have been shown to improve dissolved nutrient removal, improve hydrocarbon removal and aid TSS sequestration.
- **Interception and Evapotranspiration**: Woody vegetation typically intercepts and evapotranspires significantly more water than herbaceous vegetation, and large trees intercept and evapotranspire significantly more rain than small trees

Construction considerations include the following.

- timing of native seeding and native planting;
- weed control; and
- watering of plant material.

Caution: Seeding is generally not recommended for bioretention systems unless the bioretention system can be kept off line until the vegetation is mature, which is several years for native plants, for example, and generally not practical for bioretention projects.

Caution: It is critical to ensure that plants are watered until the plants are adequately rooted. Determine if there are nearby available sources of water for irrigation.

Construction sequence scheduling

- Temporary construction access
- Location of temporary sediment and erosion control practices to protect BMPs and downstream receiving waters
- Removal and storage of excavated material
- Installation of underground utilities

- Rough grading
- Seeding and mulching disturbed areas
- Road construction
- Final grading
- Site stabilization
- Installation of semi-permanent and permanent erosion control measures
- Removal of temporary sediment and erosion control devices

Construction observation

- Adherence to construction documents
- Verification of physical site conditions
- Erosion control measures installed appropriately

Minnesota Department of Transportation example construction protocols

Preliminary analysis and selection

Recommended number of soil borings, pits or permeameter tests for bioretention design. Designers select one of these methods.

Link to this table

Surface area of stormwater control measure (BMP)(ft^2)	Borings	Pits	Permeameter tests
< 1000	1	1	5
1000 to 5000	2	2	10
5000 to 10000	3	3	15
>10000	4[1]	4[1]	20[2]

[1]an additional soil boring or pit should be completed for each additional 2,500 ft^2 above 12,500 ft^2

[2]an additional five permeameter tests should be completed for each additional 5,000 ft^2 above 15,000 ft^2

Field verification testing prior to pond construction

- Soil hydraulic group represent what is stated in SWPPP (Stormwater Pollution Prevention Plan)
- Seasonally high water table not discovered within 3 feet of the excavated pond base within a test pit
- Commonly will test bottom of proposed pond for soil compaction (subsequent subsoil ripping) prior to media placement
- Commonly will test bottom of proposed pond for insitu infiltration rate by test pit or water filled barrel placed on pond base surface

Filter media and material testing

- Existing soil (option 1 below) or Washed sand (option 2 below), and compost certification
- Washed course aggregate choker certification
- Other treatment material certification of iron filings, activated charcoal, pH buffers, minerals, etc.
- Geotextile separation fabric certification
- Drain-tile certification (if filtration is specified)
- Seed source certification
- Barrel test verification of infiltration rate using 2.5 feet of imported 3877 Type G media

Field verification testing/inspection/verification during construction

- Water drains away in 48 hours
- Infiltration drainage rate does not exceed 8.3 inches per hour
- No tracking/equipment in pond bottom
- No sediment deposits from ongoing construction activity, media perimeter controls kept functional
- Forebay is trapping settleable solids, floating materials, and oil/grease
- Area staked off

Notice of Termination (NOT) verification

- **Option 1. Amending existing HSG soils with compost or other treatment material.** Test the infiltration rate of each infiltration basin using a double ring infiltrometer prior to completion of the basin. Conduct the test at the finished grade of the basin bottom, prior to blending the compost with the in-situ soils or sand. Ensure infiltration rates meet or exceed greater of two times the designed infiltration rate or 2 inches per hour. Conduct a minimum of five tests per representative acre of basin area and a minimum of five tests per basin. Conduct double ring infiltrometer tests in accordance with ASTM standards. Thoroughly wet test areas prior to conducting infiltrometer tests.
- **Option 2. Importing 3877 Type G Filter Topsoil Borrow (may be amended with other treatment material)**. Ensure infiltration rates meet or exceed greater of two times the designed infiltration rate or 2 inches per hour, or rate specified in the plan. Conduct a minimum of five tests per representative acre of basin area and a minimum of five tests per basin. Conduct double ring infiltrometer tests in accordance with ASTM standards. Thoroughly wet test areas prior to conducting infiltrometer tests. Amend soils with additional washed sand if rates less than specified in the contract, or compost if rates exceed 8.3 inches per hour.

The permanent stormwater management system must meet all requirements in sections 15, 16, and 17 of the CSW permit and must operate as designed. Temporary or permanent sedimentation basins that are to be used as permanent water quality management basins have been cleaned of any accumulated sediment. All sediment has been removed from conveyance systems and ditches are stabilized with permanent cover.

References

- Brown, R.A. and Hunt, W.F. (2010). *Impacts of construction activity on bioretention performance*. Journal of Hydrologic Engineering. 15(6), 386-394.
- Chaplin, Jonathan, Min Min, and Reid Pulley. 2008. Compaction Remediation for Construction Sites. Final Report. Department of Bioproducts and Biosystems Engineering, University of Minnesota, St. Paul,Minnesota.
- Cogger, C. 2005. *Potential Compost Benefits for Restoration of Soils Disturbed by Urban Development*. Compost Science & Utilization. 13.4:243-251.
- Hanks, Dallas, and A. Lewandowski, 2003. Protecting Urban Soil Quality: Examples for Landscape Codes and Specifications. USDA Natural Resources Conservation Services.
- Kees, Gary. 2008. Using Subsoiling To Reduce Soil Compaction. U.S. Forest Service Technology & Development Publication 3400 Forest Health Protection 0834-2828-MTDC.
- NRCS. 1998. Soil Quality Test Kit Guide.
- Olson, Nicholas Charles. 2010. Quantifying the Effectiveness of Soil Remediation Techniques in Compact Urban Soils. University Of Minnesota Master Of Science Thesis.

- Owen, Gordon T. 1987. *Soil disturbance associated with deep subsoiling in compact soils*. Canadian Agricultural Engineering: 33-37.
- Pennsylvania department of Environmental Protection. 2006. Pennsylvania Stormwater Best Management Practices Manual. BMP 6.7.3: Soil Amendment & Restoration. 2006.
- Pitt, R., Chen, S., Clark, S.E., Swenson, J., and Ong, C.K. 2008. *Compaction's impact on urban storm-water infiltration*. Journal of Irrigation and Drainage Engineering. 134(5):652-658.
- Schueler, T. 2000. The Compaction of Urban Soil: The Practice of Watershed Protection. Center for Watershed Protection, Ellicott City, MD. pp. 210-214.
- Schueler, T. R. Can Urban Soil Compaction Be Reversed? Technical Note #108 from Watershed Protection Techniques. 1(4): 666-669.
- Selbig, W.R., and N. Balster. 2010. Evaluation of turf-grass and prairie-vegetated rain gardens in a clay and sand soil: Madison, Wisconsin, water years 2004–08. U.S. Geological Survey, Scientific Investigation Report 2010–5077, 75 p.
- Spoor, G. & Godwin, R.J. 1978. *An experimental investigation into the deep loosening of soil by rigid tines*. Journal of Agricultural Engineering Research, 23, 243–258.
- Spoor, G., Tijink, F.G.J. & Weisskopf, P. 2003. *Subsoil compaction: risk, avoidance, identification and alleviation*. Soil and Tillage Research,73, 175–182.
- Spoor, G. 2006. *Alleviation of Soil Compaction: Requirements, Equipment and Techniques*. Soil Use and Management 22:113-122.

Operation and maintenance of bioretention

Green Infrastructure: Bioretention practices can be an important tool for retention and detention of stormwater runoff. Because they utilize vegetation, bioretention practices provide additional benefits, including cleaner air, carbon sequestration, improved biological habitat, and aesthetic value.

Information: Due to the similarities of the majority of inspection and maintenance tasks required for both bioretention practices and infiltration practices, the Operations and Maintenance sections for both bioretention and infiltration practices have been combined into a single wiki page.

The Chesapeake Stormwater Network has developed

materials that illustrate inspection and maintenance of BMP practices. These include information on visual inspections and two videos. Visit their maintenance page. **NOTE: These materials provide useful guidance but should not be used for compliance with Minnesota permits.**

The most frequently cited maintenance concern for infiltration practices is surface clogging caused by organic matter, fine silts, hydrocarbons, and algal matter. Common operational problems include

- standing water;
- clogged filter surface; and
- inlet, outlet or under-drains clogged.

Recommendations described below are aimed at preventing these common problems.

Design phase maintenance considerations

Implicit in the design guidance is the fact that many design elements of infiltration systems can minimize the maintenance burden and maintain pollutant removal efficiency. Key examples include

- limiting drainage area;
- providing easy site access (*REQUIRED*);
- providing pretreatment (*REQUIRED*); and
- utilizing native plantings (see Plants for Stormwater Design).

For more information on design information for individual infiltration practices, link here.

Construction phase maintenance

Proper construction methods and sequencing play a significant role in reducing problems with operation and maintenance (O&M). In particular, with construction of these practices, the most important action for preventing operation and maintenance difficulties is to ensure that the contributing drainage area has been fully stabilized prior to bringing the practice on line.

Warning: It is required that the contributing drainage area has been fully stabilized prior to bringing the practice on line

Inspections during construction are needed to ensure that the infiltration practice is built in accordance with the approved design and standards and specifications. Detailed inspection checklists should be used that include sign-offs by qualified individuals at

critical stages of construction, to ensure that the contractor's interpretation of the plan is acceptable to the professional designer. An example construction phase inspection checklist is provided below.

Infiltration practices construction inspection checklist.

Link to this table

To access an Excel version of form (for field use), click here.

Project:		
Location:		
Site Status:		
Date:		
Time:		
Inspector:		
Construction Sequence	**Satisfactory / Unsatisfactory**	**Comments**
1. Pre-Construction		
Pre-construction meeting		
Runoff diverted (Note type of bypass)		
Facility area cleared		
Soil tested for permeability		
Soil tested for phosphorus content (include test method)		
Verify site was not overdug		
Project benchmark near site		
Facility location staked out		
Temporary erosion and sediment protection properly installed		
2. Excavation		

Lateral slopes completely level		
Soils not compacted during excavation		
Longitudinal slopes within design range		
Stockpile location not adjacent to excavation area and stabilized with vegetation and/ or silt fence		
Verify stockpile is not causing compaction and that it is not eroding		
Was underlying soil ripped or loosened		
3. Structural Components		
Stone diaphragm installed per plans		
Outlets installed pre plans		
Underdrain installed to grade		
Pretreatment devices installed per plans		
Soil bed composition and texture conforms to specifications		
4. Vegetation		
Complies with planting specs		
Topsoil complies with specs in composition and placement		
Soil properly stabilized for permanent erosion control		
5. Final Inspection		
Dimensions per plans		
Pre-treatment operational		
Inlet/outlet operational		
Soil/ filter bed permeability verified		
Effective stand of vegetation stabilized		
Construction generated sediments removed		

Contributing watershed stabilized before flow is diverted to the practice		
Comments:		
Actions to be taken:		

Post-construction operation and maintenance

Warning: A maintenance plan clarifying maintenance responsibility is *REQUIRED*. Effective long-term operation of infiltration practices necessitates a dedicated and routine maintenance schedule with clear guidelines and schedules. Proper maintenance will not only increase the expected lifespan of the facility but will improve aesthetics and property value.

Example of a failing bioinfiltration system. Failure was due to clogging of the media surface by incoming sediment.

Inspection and maintenance planning

A maintenance plan clarifying maintenance responsibilities is REQUIRED. Effective long-term operation of bioretention and infiltration practices necessitates a dedicated and routine maintenance schedule with clear guidelines and schedules. Proper maintenance will not only increase the expected lifespan of the facility but will improve aesthetics and property value.

Some important post-construction considerations are provided below along with RECOMMENDED maintenance standards.

- A site-specific O&M plan that includes the following considerations should be prepared by the designer prior to putting the stormwater practice into operation.
  - Inspection checklists

  - Routine maintenance checklists
  - Operating instructions for outlet component
  - Vegetation maintenance schedule

- A legally binding and enforceable maintenance agreement should be executed between the practice owner and the local review authority.
- Adequate access must be provided for inspection, maintenance and landscaping upkeep, including appropriate equipment and vehicles.
- Maintenance activities should be careful not to cause compaction. No vehicles will be allowed within the footprint of the filtration or infiltration area. Foot traffic and stockpiling should be kept to a minimum.
- The surface of the ponding area may become clogged with fine sediment over time. Core aeration or cultivating of non-vegetated areas may be required to ensure adequate filtration.
- BMP areas generally should not be used as dedicated snow storage areas, but can be with the following considerations.
  - Snow storage should not occur in areas designated as potential stormwater hotspots for road salt.
  - Areas designed for infiltration should be protected from excessive snow storage where sand and salt is applied.
  - Specific snow storage areas should be assigned that will provide some filtration before the stormwater reaches the BMP areas.**NOTE: Chloride will not be attenuated in filtration BMPs.**
  - When used for snow storage, or if used to treat parking lot runoff, the BMP area should be planted with salt tolerant and non-woody plant species.
  - Practices should always be inspected for sand build-up on the surface following the spring melt event.

- General maintenance activities and schedule are provided below.

Summary of typical maintenance regime

The list below highlights the assumed maintenance regime for an infiltration or bioinfiltration basin or trench, tree trench, or dry swale with check dams. Note that some items pertain only to vegetated systems.

- First year after planting
  - Adequate water is crucial to plant survival and temporary irrigation will be needed unless rainfall is adequate until plants mature

- As needed
  - Prune and weed to maintain appearance

- Stabilize or replace mulch when erosion is evident
  - Remove trash and debris
  - Mow filter strip
  - Renew mulch to replace that which has decomposed
  - Replace vegetation whenever percent cover of acceptable vegetation falls below 90 percent or project specific performance requirements are not met. If vegetation suffers for no apparent reason, consult with horticulturist and/or test soil as needed
- Semi-annually
  - Inspect inflow and pretreatment systems for clogging (off-line systems) and remove any sediment
  - Inspect filter strip/grass channel for erosion or gullying. Sod as necessary
  - Herbaceous vegetation, trees and shrubs should be inspected to evaluate their health and replanted as appropriate to meet project goals
  - Remove any dead or severely diseased vegetation
- Annually in fall
  - Inspect and remove any sediment and debris build-up in pretreatment areas
  - Inspect inflow points and infiltration surface for buildup of road sand associated with spring melt period, remove as necessary, and replant areas that have been impacted by sand/salt build up

Maintenance of vegetated infiltration practices is critical during the establishment period. Although some plants look healthy in this photo, maintenance is needed to remove sediment from the filter strip and inflow area, remove weeds from the basin, re-vegetate some ares, and add mulch to some areas.

- Annually in spring
  - Cut back and remove previous year’s plant material and remove accumulated leaves if needed (or controlled burn where appropriate)

Estimated hours to perform maintenance activities

All estimated hours listed below would be to perform maintenance on a commercially sized bioinfiltration or bioretention basin approximately 1,000 square feet in size that has adequate pretreatment, has been planted with containerized plants, and mulched appropriately.

- **Plant Establishment Period (First two years)**
  - Bi-monthly weeding – 4 visits at 3 hours per visit
  - Plant replacement – 1 replacement planting in the Fall, 4 hours (assuming 10 percent plant loss)
  - Spring cleanup (cut back of previous years vegetation) –2 hours
  - Erosion, sediment, and pretreatment cleanout – 1 hour (assuming vacuum truck clean-out of sump catch basin or sediment fore bay)
- **Regular Maintenance (After first two years)**
  - Bi-monthly weeding – 4 visits at 2 hours per visit
  - Plant replacement – 1 replacement planting in the Fall, 2 hours (assuming 5 percent plant loss)
  - Spring cleanup (cut back of previous years vegetation) – 4 hours
  - Tree and shrub pruning – 2 hours (every third year)
  - Erosion, sediment, and pretreatment clean-out – 4 Hours (assuming vacuum truck clean-out of sump catch basin or sediment forebay once per year and at least one bi-yearly sediment removal from the bottom of the basin)

Erosion protection and sediment monitoring, removal, and disposal – protecting your investment

Regular inspection of not only the BMP but also the immediate surrounding catchment area is necessary to ensure a long lifespan of the water quality improvement feature. Erosion should be identified as soon as possible to avoid the contribution of significant sediment to the BMP.

Pretreatment devices need to be maintained for long-term functionality of the entire BMP. Accumulated sediment in forebays, filter strips, water quality sump catch basins, or any pretreatment features will need to be inspected yearly. Timing of cleaning of these features is dependent on their design and sediment storage capabilities. In watersheds with erosion or high sediment loadings, the frequency of clean out will likely be increased. A vacuum truck is typically used for sediment removal. It is possible that any sediment removed from pretreatment devices or from the bottom of a basin may contain high levels of pollutants. All sediments, similar to those retrieved from a stormwater pond during dredging, may be subjected to the MPCA's guidance for reuse and disposal.

If a grassed filter strip or swale is used as pretreatment, they should be mowed as frequently as a typical lawn. Depending on the contributing watershed, grassed BMPs may also need to be swept before mowing. All grassed BMPs should be swept annually with a

stiff bristle broom or equal to remove thatch and winter sand. The University of Minnesota's Sustainable Urban Landscape Series website provides guidance for turf maintenance, including mowing heights.

Sediment loading can potentially lead to a drop in infiltration or filtration rates. It is recommended that infiltration performance evaluations follow the four level assessment systems in Stormwater Treatment: Assessment and Maintenance (Gulliver et al., 2010).

Seeding, planting, and landscaping maintenance – keeping it looking good

Plant selection during the design process is essential to limit the amount of maintenance required. It is also critical to identify who will be maintaining the BMP in perpetuity and to design the plantings or seedings accordingly. The decision to install containerized plants or to seed will dictate the appearance of the BMP for years to come. If the BMP is designed to be seeded with an appropriate native plant based seed mix, it is essential the owner have trained staff or the ability to hire specialized management professionals. Seedings can provide plant diversity and dense coverage that helps maintain drawdown rates, but landscape management professionals that have not been trained to identify and appropriately manage weeds within the seeding may inadvertently allow the BMP to become infested and the designed plant diversity be lost. The following are minimum requirements for seed establishment and plant coverage.

This bioretention basin utilizes several native species.

- At least 50 percent of specified vegetation cover at end of the first growing season, not including REQUIRED cover crop
- At least 90 percent of specified vegetation cover at end of the third growing season
- Supplement plantings to meet project specifications if cover requirements are not met
- Tailor percent coverage requirements to project goals and vegetation. For example, percent cover required for turf after one growing season would likely be 100 percent, whereas it would be lower for other vegetation types.

For information on plant selection, link here.

For proper nutrient control, bioretention BMP's must not be fertilized unless a soil test from a certified lab indicates nutrient deficiency. An exception is a one-time fertilizer application during planting of the cell, which will help with plant establishment. Irrigation is also typically needed during establishment.

Weeding is especially important during the plant establishment period, when vegetation cover is not 100 percent yet. Some weeding will always be needed. It is also important to budget for some plant replacement (at least 5 to 10 percent of the original plantings or seedings) during the first few years in case some of the plants or seed that were originally installed don't become vigorous. It is highly recommended that the install contractor be responsible for a plant warranty period. Typically, plant warranty periods can be 60 days or up to one year from preliminary acceptance through final inspections. If budget allows, installing larger plants (#1 Cont. vs 4" Pot) during construction can decrease replacement rates if properly cared for during the establishment period.

Weeding in years after initial establishment should be targeted and thorough. Total eradication of aggressive weeds at each maintenance visit will ultimately reduce the overall effort required to keep the BMP weed free. Mulch is highly effective at preventing weeds from establishing while helping retain moisture for plant health. Mulch renewal will be needed two or three times after establishment (first five years). After that, the plants are typically dense enough to require less mulching, and the breakdown of plant material will provide enough organic matter to the infiltration/filtration practice.

Rubbish and trash removal will likely be needed more frequently than in the adjacent landscape. Trash removal is important for prevention of mosquitoes and for the overall appearance of the BMP.

Sustainable service life for infiltration and bioretention BMPs

The service life of infiltration practices depends upon the pollutant of concern.

Infiltration rate service life before clogging

Infiltration rate appears to drop immediately after installation and then level off at a sustainable level (Jenkins et al., 2010; Barrett et al., 2013). Planted bioretention columns even showed a slight increase in infiltration rate after the initial drop (Barrett et al., 2013). Plant roots are essential in macropore formation, which help to maintain the infiltration rate. If proper pretreatment is present, service life for infiltration should be unlimited. However, if construction site runoff is not kept from entering the infiltration cell, clogging will occur, limiting or eliminating the infiltration function of the system, thus requiring restorative maintenance or repair (Brown and Hunt, 2012).

Nitrogen reduction

An important mechanism of nitrogen removal in vegetated infiltration systems is plant uptake since nitrogen is essential for plant growth. If the BMP has an internal water storage zone, soluble nitrogen is also removed through denitrification, a microbially-mediated process that only occurs under anoxic conditions. Denitrification requires organic matter as a carbon source, which is supplied by decaying root matter and mulch. Particulate bound nitrogen in stormwater runoff will typically be removed through sedimentation. All of these processes are self-sustaining, and the service life of an infiltration system designed for nitrogen reduction should be very long. In oxygenated systems where denitrification is not an important process, leaching of nitrate is likely. In systems having soils with a high organic matter content, organic nitrogen can be converted to nitrate, resulting in additional loss of nitrogen through leaching (Liging and Davis, 2014).

Phosphorus reduction

With design optimized for phosphorus reduction, service life can be more than three decades (Lucas and Greenway, 2011c). Sediment bound phosphorus is removed through sedimentation, while removal of soluble phosphorus in bioretention depends on the type of media used. If the media is already saturated with P (i.e. its P binding sites are full), it will not be able to retain additional dissolved P and the P in stormwater will tend to leach from the media as it passes through the biofilter (Hunt et al., 2006). It is highly recommended that the P-index of the media at installation be below 30, which equates to less than 36 milligrams per kilogram P, to ensure P removal capacity. Laboratory research has suggested an oxalate extractable P concentration of 20 to 40 milligrams per liter will provide consistent removal of P (O'Neill and Davis, 2012). After an effective loading of the equivalent of more than three decades of P into bioretention mecocosms optimized for P reduction, researchers in Australia showed that excellent P retention was still occurring. Keys to maximize P reduction in these systems included P sorptive soils or soil amendments (e.g. aluminum water treatment residuals [WTR] or Krasnozem soils [K40], a highly aggregated clay), use of coir peat (a source of organic matter low in phosphorus), and healthy vegetation. The systems with aluminum water treatment residuals still retained up to 99 percent of applied PO4-P in storm water after the equivalent of 32 years of treatment. After 110 weeks of effluent loading at typical stormwater concentrations, the equivalent of 48 years of bioretention loads, phosphate retention from storm water by the K40 soils treatment was 85 percent. "Comparison with the K40 treatments over the loading and dosing regimes suggest that the WTR treatments will perform at least as well as the K40 treatment under similar exposure of 48 years" (Lucas and Greenway, 2011).

Heavy metals retention

Metals are typically retained in infiltration systems through sedimentation and adsorption processes. Since there are a finite amount of sorption sites for metals in a particular soil, there will be a finite service life for the removal of dissolved metals. Morgan et al. (2011) investigated cadmium, copper, and zinc removal and retention with batch and column experiments. Using synthetic

stormwater at typical stormwater concentrations, they found that 6 inches of filter media composed of 30 percent compost and 70 percent sand will last 95 years until breakthrough (i.e. when the effluent concentration is 10 percent of the influent concentration). They also found that increasing compost from 0 percent to 10 percent more than doubles the expected lifespan for 10 percent breakthrough in 6 inches of filter media for retainage of cadmium and zinc. Using accelerated dosing laboratory experiments, Hatt et al. (2011) found that breakthrough of Zn was observed after 2000 pore volumes, but did not observe breakthrough for Cd, Cu, and Pb after 15 years of synthetic stormwater passed through the media. However, concentrations of Cd, Cu, and Pb on soil media particles exceeded human and/or ecological health levels, which could have an impact on disposal if the media needed replacement. Since the majority of metals retainage occurs in the upper 2 to 4 inches of the soil media (Li and Davis, 2008), long-term metals capture may only require rejuvenation of the upper portion of the media.

Polycyclic aromatic hydrocarbons (PAHs) reduction

Accumulation of polycyclic aromatic hydrocarbons (PAHs) in sediments has been found to be so high in some stormwater retention ponds that disposal costs for the dredging spoils were prohibitively high. Research has shown that rain gardens, on the other hand, are “a viable solution for sustainable petroleum hydrocarbon removal from stormwater, and that vegetation can enhance overall performance and stimulate biodegradation.” (Lefevre, 2012b).

Typical maintenance problems and activities for infiltration practices

The following table summarizes common maintenance concerns, suggested actions, and recommended maintenance schedule.

Typical maintenance problems and activities for infiltration practices
Link to this table

Inspection Focus	Common Maintenance Problems	Maintenance Activity	Recommended Maintenance Schedule	Applicable Infiltration Practices[1]
Drainage Area and Drawdown Time	Clogging, sediment deposition	Ensure that contributing catchment areas to practice, and inlets are clear of debris	Monthly	1,2,3,4,5,6,7
	Erosion of	In case of severely reduced drawdown time, scrape bottom of	Upon	1,2,3,4,5,6

	catchment area contributing significant amount of sediment	basin and remove sediment. Disc or otherwise aerate/scarify basin bottom. De-thatch if basin bottom is turf grass. Restore original design cross section or revise section to increase infiltration rate and restore with vegetation as necessary.	identification of drawdown times longer than 48 hours or upon complete failure	
Pretreatment	Pretreatment screens or sumps reach capacity	Remove sediment and oil/grease from pretreatment devices/structures.	Minimum yearly or as per manufacturer's recommendations	1,2,3,4,5
	Vegetative filter strip failure	Reduce height of vegetative filter strip that may be limiting in-flow. Re-establish vegetation to prevent erosion. Leave practice off-line until full reestablishment.	Mow grass filter strips monthly. Restore as necessary	1,2,4,6
Site Erosion	Scouring at inlets	Correct earthwork to promote non-erosive flows that are evenly distributed	As necessary	1,2,3,6
	Unexpected flow paths into practice	Correct earthwork to eliminate unexpected drainage or created additional stable inlets as necessary	As necessary	1,2,3,6
Vegetation	Reduced drawdown time damaging plants	Correct drainage issues as described above	Replace with appropriate plants after correction of drainage issues	2,6,8
	Severe weed establishment	Limit the ability for noxious weed establishment by properly mowing, mulching or timely herbicide or hand weeding. Refer to the MDA Noxious Weed List	Bi-monthly April through October	2,6,8

[1]1=Infiltration Basin; 2=Bioinfiltration Basin; 3=Infiltration Trench; 4=Dry Well; 5=Underground Infiltration; 6=Dry Swale with Check Dams; 7=Permeable Pavement; 8=Tree Trench/Tree Box

Maintenance agreements

A Maintenance Agreement is a legally binding agreement between two parties, and is defined as ”a nonpossessory right to use and/or enter onto the real property of another without possessing it.“ Maintenance Agreements are often required for the issuance of a permit for construction of a stormwater management feature and are written and approved by legal counsel. Maintenance Agreements are often similar to Construction Easements. A Maintenance Agreement is required for one party to define and enforce maintenance by another party. The Agreement also defines site access and maintenance of any features or infrastructure if the property owner fails to perform the required maintenance.

Maintenance Agreements are commonly established for a defined period such as five years for a residential site or 10 to 20 years for a commercial/governmental site after construction of the infiltration practice. Maintenance agreements often define the types of inspection and maintenance that would be required for that infiltration practice and what the timing and duration of the inspections and maintenance may be. Essential inspection and maintenance activities include but are not limited to drawdown time, sediment removal, erosion monitoring and correction, and vegetative maintenance and weeding. If maintenance is required to be performed due to failure of the site owner to properly maintain the infiltration practices, payment or reimbursement terms of the maintenance work are defined in the Agreement. Below is an example list of maintenance standards from an actual Maintenance Agreement.

1. Plants shall be watered daily for two weeks after the garden installation is complete.
2. In the first year, rainwater gardens require vigilant weeding and should be weeded monthly. The need for weeding will decrease as plants become established.
3. Dead plant material and garbage or other debris shall be removed from the rain garden.
4. Areas devoid of mulch shall be re-mulched on an annual basis.
5. The rainwater garden shall be inspected annually for sediment trapped in the pretreatment area and in the garden itself. If possible, accumulated sediment should be removed.
6. Shrubs shall be pruned as necessary to keep a neat appearance.
7. Plants that do not survive shall be removed and replanted.
8. Side slopes must be inspected for erosion and the formation of rills or gullies at least annually and erosion problems must be corrected immediately.
9. If gardens are properly planned and designed (protected from sediment and compaction and incorporating a sufficient turf pretreatment area), a rainwater basin is likely to retain its effectiveness for well over 20 years. After that time, inspection will reveal whether sedimentation warrants scraping out the basin and replanting it (possibly with salvaged plants).

In some project areas, a drainage easement may be required. Having an easement provides a mechanism for enforcement of maintenance agreements to help ensure infiltration practices are maintained and functioning. Drainage Easements also require that the land use not be altered in the future. Drainage Easements exist in perpetuity and are required property deed amendment to be passed down to all future property owners.

As defined by the Maintenance Agreement, the landowner should agree to provide notification immediately upon any change of the legal status or ownership of the property. Copies of all duly executed property transfer documents should be submitted as soon as a property transfer is made final.

- Example Maintenance Agreement 1
- Example Maintenance Agreement 2
- Example Maintenance Agreement 3

Maintenance inspection reports

- Maintenance inspection report for infiltration basins
  - upload MS Word version File:Maintenance inspection report for infiltration basins.docx
- Maintenance inspection report for bioinfiltration basins
  - upload MS Word version File:Maintenance inspection report for bioinfiltration basins.docx
- Maintenance inspection report for infiltration trench
  - upload MS Word version File:Maintenance inspection report for infiltration trench.docx
- Maintenance inspection report for dry well
  - upload MS Word version File:Maintenance inspection report for dry well.docx
- Maintenance inspection report for underground infiltration facilities
  - upload MS Word version File:Maintenance inspection report for underground infiltration facilities.docx
- Maintenance inspection report for dry swale with check dams
  - upload MS Word version File:Maintenance inspection report for dry swale with check dams.docx
- Maintenance inspection report for permeable pavement
  - upload MS Word version File:Maintenance inspection report for permeable pavement.docx

- Maintenance inspection report for tree trench/tree box
  - upload MS Word version File:Maintenance inspection report for tree trench-tree box.docx

Link to Chesapeake Stormwater visual indicators form.

References

- Aprill, W. and Sims, Ronald C. 1990. *Evaluation of the Use of Prairie Grasses for Stimulating Polycyclic Aromatic Hydrocarbon Treatment in Soil*. Biological Engineering Faculty Publications. Paper 41.
- Brown, R.A. and Hunt, W.F. 2010. *Impacts of construction activity on bioretention performance*. Journal of Hydrologic Engineering. 15(6), 386-394.
- Gulliver, J.S., A.J. Erickson, and P.T. Weiss (editors). 2010. Stormwater Treatment: Assessment and Maintenance. University of Minnesota, St. Anthony Falls Laboratory. Minneapolis, MN.
- Hatt, B.E., Steinel, A., Deletic, A., and Fletcher, T.D. 2011. *Retention of heavy metals by stormwater filtration systems: Breakthrough analysis*. Water, Science, and Technology. 64(9), 1913-1919.
- Henderson, C.F.K. 2009. *The Chemical and Biological Mechanisms of Nutrient Removal from Stormwater in Bioretention Systems*. Thesis. Griffith School of Engineering, Griffith University.
- Hunt, W.F., Jarrett, A.R., Smith, J.T., and Sharkey, L.J. 2006. *Evaluating bioretention hydrology and nutrient removal at three field sites in North Carolina*. Journal of Irrigation and Drainage Engineering. 132(6), 600-608.
- Jenkins, G, J.K., Wadzuk, B.M., and Welker, A.L. 2010. *Fines accumulation and distribution in a storm-water rain garden nine year postconstruction*. Journal of Irrigation and Drainage Engineering. 136(12), 862-869.
- LeFevre, G.H., M. Raymond, P. Hozalski, J. Novak. 2012a. *The role of biodegradation in limiting the accumulation of petroleum hydrocarbons in raingarden soils*. Water Research 46: 6753-6762.
- Lefevre, G.H., P.J. Novak, R.M. Hozalski. 2012b. *Fate of naphthalene in laboratory-scale bioretention cells: implications for sustainable stormwater management*. Environmental Science and Technology 46(2):995-1002.
- Li, H. and Davis, A.P. 2008. *Heavy metal capture and accumulation in bioretention media*. Environmental Science & Technology. 42, 5247-5253.
- Liging, Li, and A.P. Davis. 2014. *Urban stormwater runoff nitrogen composition and fate in bioretention systems*. Accepted for publication in ES&T.
- Lucas, W.C. 2005. Green Technology: The Delaware Urban Runoff Management Approach. Prepared For Delaware Department of Natural Resources And Environmental Control Division of Soil And Water Conservation.
- Lucas, , W. C. and M. Greenway. 2007a. A Comparative Study of Nutrient Retention Performance In Vegetated and Non-Vegetated Bioretention Mecocosms. Novatech 2007 Session 5.2.

- Lucas, W. C. and M. Greenway. 2007b. *Phosphorus Retention Performance in Vegetated and Non-Vegetated Bioretention Mecocosms Using Recycled Effluent*. Conference Proceedings: Rainwater and Urban Design Conference 2007.
- Lucas, W. C. and M. Greenway. 2008. *Nutrient Retention in Vegetated and Non-vegetated Bioretention Mesocosms.* Journal of Irrigation and Drainage Engineering. 134 (5): 613-623.
- Lucas, W. C. and M. Greenway. 2011a. *Hydraulic Response and Nitrogen Retention in Bioretention Mesocosms with Regulated Outlets: Part I—Hydraulic Response*. Water Environment Research 83(8): 692-702.
- Lucas, W. C. and M. Greenway. 2011b. *Hydraulic response and nitrogen retention in bioretention mesocosms with regulated outlets: part II--nitrogen retention*. Water Environment Research 83(8): 703-13.
- Lucas, W. C. and M. Greenway. 2011c. *Phosphorus Retention by Bioretention Mesocosms Using Media Formulated for Phosphorus Sorption: Response to Accelerated Loads*. Journal of Irrigation and Drainage Engineering. 137(3): 144–153.
- Morgan, J.G., K.A. Paus, R.M. Hozalski and J.S. Gulliver. (2011). Sorption and Release of Dissolved Pollutants Via Bioretention Media. SAFL Project Report No. 559, September 2011.
- O'Neill, S.W. and Davis, A.P. (2012). *Water treatment residual as a bioretention amendment for phosphorus. I: Evaluation studies*. Journal of Environmental Engineering. 138(3), 318-327.

Useful links

- Chesapeake Stormwater Network TECHNICAL BULLETIN No. 10. Bioretention Illustrated: A Visual Guide for Constructing, Inspecting, Maintaining and Verifying the Bioretention Practice
- Archived webcast from Chesapeake Stormwater Network - TRUST BUT VERIFY: Urban BMP Verification in the Chesapeake Bay

Assessing the performance of bioretention

Green Infrastructure: Bioretention practices can be an important tool for retention and detention of stormwater runoff. Because they utilize vegetation, bioretention practices provide additional benefits, including cleaner air, carbon sequestration, improved biological habitat, and aesthetic value.

Biofiltration (bioretention with underdrains) is designed to retain solids and associated pollutants by filtering. A typical method for assessing the performance of of BMPs with underdrains is therefore measuring and comparing pollutant concentrations at the

influent and effluent. BMPs without underdrains are more difficult to assess, although considering only potential impacts to surface waters, a properly functioning infiltration system is considered to be highly performing.

An online manual for assessing BMP treatment performance was developed in 2010 by Andrew Erickson, Peter Weiss, and John Gulliver from the University of Minnesota and St. Anthony Falls Hydraulic Laboratory. The manual advises on a four-level process to assess the performance of a Best Management Practice.

- Level 1: Visual Inspection. This includes assessments for infiltration practices and for filtration practices. The website includes links to a downloadable checklist.
- Level 2: Capacity Testing. Level 2 testing can be applied to both infiltration and filtration practices.
- Level 3: Synthetic Runoff Testing for infiltration and filtration practices. Synthetic runoff test results can be used to develop an accurate characterization of pollutant retention or removal, but can be limited by the need for an available water volume and discharge.
- Level 4: Monitoring for infiltration or filtration practices

Level 1 activities do not produce numerical performance data that could be used to obtain a stormwater management credit. BMP owners and operators who are interested in using data obtained from Levels 2 and 3 should consult with the MPCA or other regulatory agency to determine if the results are appropriate for credit calculations. Level 4, Monitoring, is the method most frequently used for assessment of the performance of a BMP.

Use these links to obtain detailed information on the following topics related to BMP performance monitoring:

- Developing an Assessment Program
- Water Budget Measurement
- Sampling Methods
- Analysis of Water and Soils
- Data Analysis for Monitoring

Additional information on designing a monitoring network and performing field monitoring are found at this link.

Cost/benefit considerations for bioretention

Cost/benefit considerations for bioretention

Calculating credits for bioretention

Warning: Models are often selected to calculate credits. The model selected depends on your objectives. For compliance with the Construction Stormwater permit, the model must be based on the assumption that an instantaneous volume is captured by the BMP.

Green Infrastructure: Bioretention practices can be an important tool for retention and detention of stormwater runoff. Because they utilize vegetation, bioretention practices provide additional benefits, including cleaner air, carbon sequestration, improved biological habitat, and aesthetic value.

Recommended pollutant removal efficiencies, in percent, for biofiltration BMPs. Sources. NOTE: removal efficiencies are 100 percent for water that is infiltrated.

TSS=total suspended solids; TP=total phosphorus; PP=particulate phosphorus; DP=dissolved phosphorus; TN=total nitrogen

TSS	TP	PP	DP	TN	Metals	Bacteria	Hydrocarbons
85	link to table	link to table	link to table	50	35	95	80

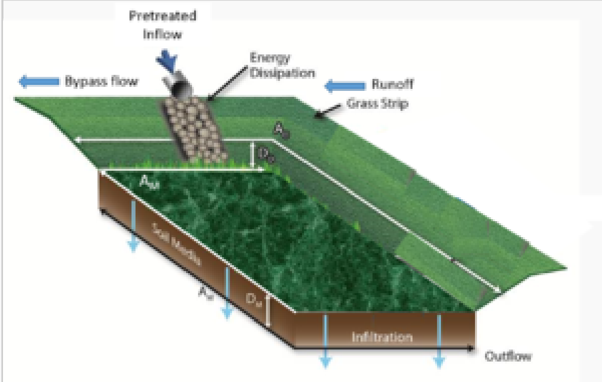
Credit refers to the quantity of stormwater or pollutant reduction achieved either by an individual Best Management Practice (BMP) or cumulatively with multiple BMPs. Stormwater credits are a tool for local stormwater authorities who are interested in

- providing incentives to site developers to encourage the preservation of natural areas and the reduction of the volume of stormwater runoff being conveyed to a best management practice (BMP);
- complying with permit requirements, including antidegradation (see [5]; [6]);
- meeting the MIDS performance goal; or
- meeting or complying with water quality objectives, including Total Maximum Daily Load (TMDL) Wasteload Allocations (WLAs).

This page provides a discussion of how bioretention practices can achieve stormwater credits. Bioretention systems with and without underdrains are both discussed, with separate sections for each type of system as appropriate. In this discussion, bioretention systems with an underdrain are called biofiltration systems, while bioretention systems with no underdrain are called bioinfiltration systems.

Overview

Bioretention is a terrestrial-based (up-land as opposed to wetland) water quality and water quantity control process. Bioretention consists of an engineered soil media layer designed to treat stormwater runoff via filtration through plant and soil media, evapotranspiration from plants, or through infiltration into underlying soil. Pretreatment is REQUIRED for all bioretention facilities to settle particulates before entering the BMP. Bioretention practices may be built with or without an underdrain. Other common components of bioretention systems may include a stone aggregate layer to allow for increased retention storage and an impermeable liner on the bottom or sides of the facility if located near buildings, subgrade utilities, or in karst formations. Bioretention is a versatile stormwater treatment method applicable to all types of settings such as landscaping islands, cul-de-sacs, parking lot margins, commercial setbacks, open space, rooftop drainage, and streetscapes.



Schematic illustrating the components and processes for a bioinfiltration system.

Systems with no underdrain are called bioinfiltration, while those with an underdrain are called biofiltration. Biofiltration, commonly termed bioretention with underdrains, is primarily a stormwater quality control practice. Some water quantity reduction can be achieved through infiltration below the underdrain, particularly if the underdrain is raised above the bottom of the BMP, and through evapotranspiration. Biofiltration includes an underdrain layer to collect the filtered runoff for downstream discharge.

Schematic illustrating the components and processes for a biofiltration system.

See Bioretention terminology for a discussion of different types of bioretention systems. Although tree trenches and tree boxes are a form of bioretention, they are discussed separately in this manual.

Warning: The Construction Stormwater permit REQUIRES pretreatment for bioretention practices

Pollutant removal mechanisms

Bioretention practices have one of the highest nutrient and pollutant removal efficiencies of any BMP (Mid-America Regional Council and American Public Works Association Manual of Best Management Practice BMPs for Stormwater Quality, 2012). Bioretention provides pollutant removal and volume reduction through filtration, evaporation, infiltration, transpiration, biological and microbiological uptake, and soil adsorption; the extent of these benefits is highly dependent on site specific conditions and design. In addition to phosphorus and total suspended solids (TSS), which are discussed in greater detail below, bioretention treats a wide variety of other pollutants.

Removal of phosphorus is dependent on the engineered media. Media mixes with high organic matter content typically leach phosphorus and can therefore contribute to water quality degradation. The Manual provides a detailed discussion of media mixes, including information on phosphorus retention.

Location in the treatment train

Stormwater treatment trains are multiple BMPs that work together to minimize the volume of stormwater runoff, remove pollutants, and reduce the rate of stormwater runoff being discharged to Minnesota wetlands, lakes and streams. Bioretention facilities are typically located in upland areas of the stormwater treatment train, controlling stormwater runoff close to the source.

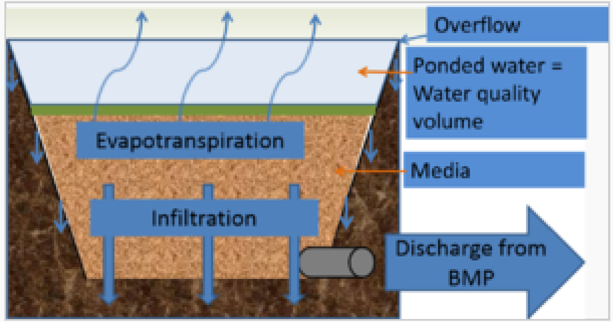
Methodology for calculating credits

This section describes the basic concepts and equations used to calculate credits for volume, Total Suspended Solids (TSS) and Total Phosphorus (TP). Specific methods for calculating credits are discussed later in this article.

Bioinfiltration practices generate credits for volume, TSS, and TP. Biofiltration practices do not substantially reduce the volume of runoff but may qualify for a partial volume credit as a result of evapotranspiration, infiltration occurring through the sidewalls above the underdrain, and infiltration below the underdrain piping. Bioretention practices are effective at reducing concentrations of other pollutants including nitrogen, metals, bacteria, and hydrocarbons. This article does not provide information on calculating credits for pollutants other than TSS and TP, but references are provided that may be useful for calculating credits for other pollutants.

Assumptions and approach

In developing the credit calculations, it is assumed the bioretention practice is properly designed, constructed, and maintained in accordance with the Minnesota Stormwater Manual. If any of these assumptions is not valid, the BMP may not qualify for credits or credits should be reduced based on reduced ability of the BMP to achieve volume or pollutant reductions. For guidance on design, construction, and maintenance, see the appropriate article within the bioretention section of the Manual.



Schematic illustrating the water quality volume (V_{WQ}) for a bioretention BMP. The V_{WQ} equals the volume of water ponded above the media and below the overflow point in the BMP. The schematic illustrates other processes occurring within the bioretention system. In this example, an underdrain is located at the bottom of the practice.

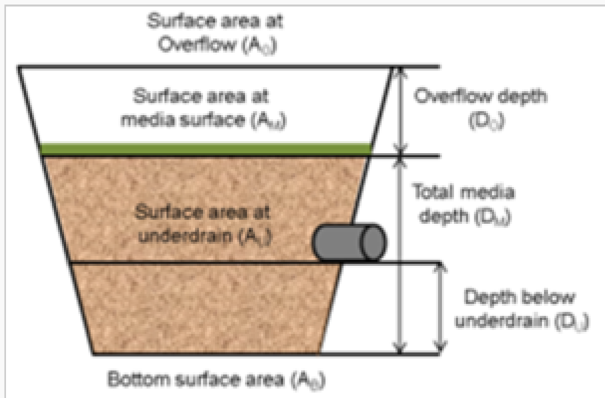
Warning: Pre-treatment is required for all bioretention practices

In the following discussion, the water quality volume (V_{WQ}) is delivered instantaneously to the BMP. The V_{WQ} is stored as water ponded above the filter media and below the overflow point in the BMP. The V_{WQ} can vary depending on the stormwater management objective(s). For construction stormwater, V_{WQ} is 1 inch off new impervious surface. For MIDS, V_{WQ} is 1.1 inches.

In reality, some water will infiltrate through the bottom and sidewalls of the BMP as a rain event proceeds. The instantaneous volume method therefore may underestimate actual volume and pollutant losses.

Volume credit calculations - no underdrain

Volume credits are calculated based on the capacity of the BMP and its ability to permanently remove stormwater runoff via infiltration into the underlying soil from the existing stormwater collection system. These credits are assumed to be instantaneous values entirely based on the capacity of the BMP to capture, store, and transmit water in any storm event. Because the volume is calculated as an instantaneous volume, the water quality volume (V_{WQ}) is assumed to pond below the overflow elevation and above the bioretention media. This entire volume is assumed to infiltrate through the bottom of the BMP. The volume credit (V_{inf_b}) for infiltration through the bottom of the BMP into the underlying soil, in cubic feet, is given by



$V_{inf_b} = D_o\ (A_O + A_M)\ / 2$

Schematic illustrating terms and dimensions used for volume and pollutant calculations.

where

- A_O is the overflow surface area of the bioretention system, in square feet;
- A_M is the area at the surface of the media, in square feet; and
- D_O is the ponded depth with the BMP, in feet.

Some of the V_{WQ} will be lost to evapotranspiration rather than all being lost to infiltration. In terms of a water quantity credit, this differentiation is unimportant, but it may be important if attempting to calculate actual infiltration into the underlying soil.

The annual volume captured and infiltrated by the BMP can be determined with appropriate modeling tools, including the MIDS calculator. Example values are shown below for a scenario using the MIDS calculator. For example, a permeable pavement system designed to capture 1 inch of runoff from impervious surfaces will capture 89 percent of annual runoff from a site with B (SM) soils.

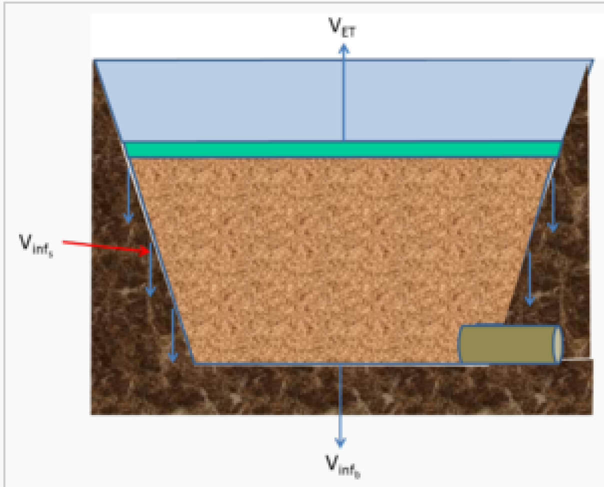
Annual volume, expressed as a percent of annual runoff, treated by a BMP as a function of soil and water quality volume. See footnote[1] for how these were determined.
Link to this table

Soil	Water quality volume (V_{WQ}) (inches)				
	0.5	**0.75**	**1.00**	**1.25**	**1.50**
A (GW)	84	92	96	98	99
A (SP)	75	86	92	95	97
B (SM)	68	81	89	93	95
B (MH)	65	78	86	91	94
C	63	76	85	90	93

[1]Values were determined using the MIDS calculator. BMPs were sized to exactly meet the water quality volume for a 2 acre site with 1 acre of impervious, 1 acre of forested land, and annual rainfall of 31.9 inches.

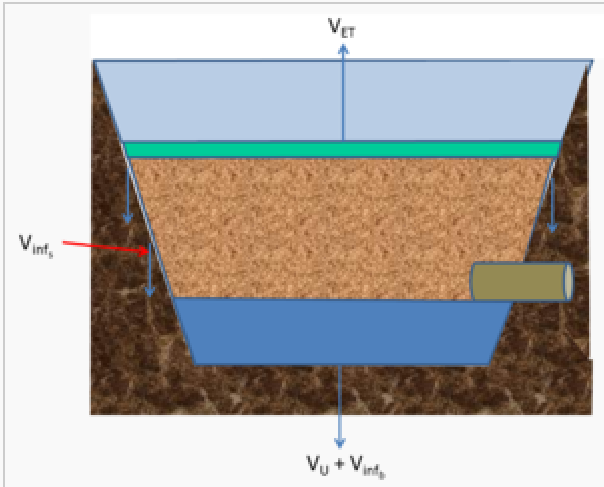
Volume credit calculations - underdrain

Volume credits for biofiltration are available only if the BMP permanently removes a portion of the stormwater runoff via infiltration through sidewalls or beneath the underdrain piping, or through evapotranspiration. These credits are assumed to be instantaneous values based on the design capacity of the BMP for a specific storm event. Instantaneous volume reduction, also termed event based volume reduction, can be converted to annual volume reduction percentages using the MIDS calculator or other appropriate modeling tools.



Schematic illustrating the different water loss terms for a biofiltration BMP with an underdrain at the bottom.

Volume credits for biofiltration basins with underdrains are calculated by a combination of infiltration through the unlined sides and bottom of the basin, the volume loss through evapotranspiration (ET), and the retention volume below the underdrain, if applicable (this is based on the assumption that this stored water will infiltrate into the underlying soil). The main design variables impacting the volume credits include whether the underdrain is elevated above the native soils and if an impermeable liner on the sides or bottom of the basin is used. Other design variables include surface area at overflow, media top surface area, underdrain location, and basin bottom locations, total depth of media, soil water holding capacity and media porosity, and infiltration rate of underlying soils.



> **Information:** For the following equations, units most commonly used in practice are given and unit correction factors are based on those units

The volume credit (V) for biofiltration basins with underdrains, in cubic feet, is given by

$V = V_{inf_B} + V_{inf_s} + V_{ET} + V_U$

where:

V_{inf_b} = volume of infiltration through the bottom of the basin (cubic feet);
V_{inf_s} = volume of infiltration through the sides of the basin (cubic feet);
V_{ET} = volume reduction due to evapotranspiration (cubic feet); and
V_U = volume of water stored beneath the underdrain that will infiltrate into the underlying soil (cubic feet).

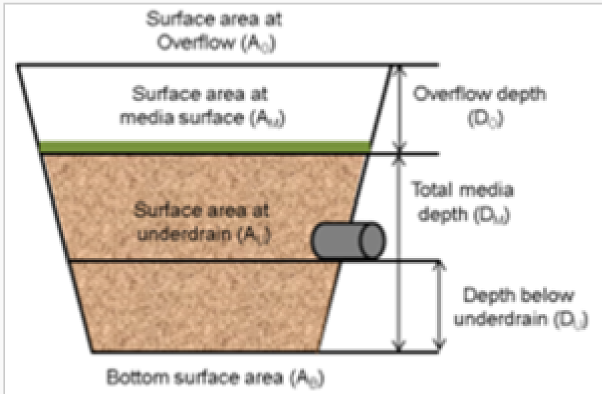
Schematic illustrating the different water loss terms for a biofiltration BMP with a raised underdrain.

Volume credits for infiltration through the bottom of the basin (V_{inf_b}) are accounted for only if the bottom of the basin is not lined. As long as water continues to draw down, some infiltration will occur through the bottom of the BMP. However, it is assumed that when an underdrain is included in the installation, the majority of water will be filtered through the media and exit through the underdrain. Because of this, the drawdown time is likely to be short. Volume credit for infiltration through the bottom of the basin is given by

$V_{inf_B} = A_B\ DDT\ I_R/12$

where

I_R = design infiltration rate of underlying soil (inches per hour);
A_B = surface area at the bottom of the basin (square feet); and
DDT = drawdown time for ponded water (hours).



Schematic illustrating terms and dimensions used for volume and pollutant calculations.

Information: The MIDS calculator assigns a default value of 0.06 inches per hour, equivalent to a D soil, to I_R. This is based on the assumption that most water will drain to the underdrain, but that some loss to underlying soil will occur. A conservative approach assuming a D soil was thus chosen.

The drawdown time is typically a maximum of 48 hours, which is designed to be protective of plants grown in the media. The Construction Stormwater permit requires drawdown within 48 hours and recommends 24 hours when discharges are to a trout stream. With a properly functioning underdrain, the drawdown time is likely to be considerably less than 48 hours.

Volume credit for infiltration through the sides of the basin is accounted for only if the sides of the basin are not lined with an impermeable liner. Volume credit for infiltration through the sides of the basin is given by

$V_{inf_s} = (A_O - A_U)\ DDT\ I_R/12$

where

A_O = the surface area at the overflow (square feet); and
A_U = the surface area at the underdrain (square feet).

Information: The MIDS calculator assigns a default value of 0.06 inches per hour, equivalent to a D soil, to I_R. This is based on the assumption that most water will drain to the underdrain, but that some loss to underlying soil will occur. A conservative approach assuming a D soil was thus chosen.

This equation assumes water will infiltrate through the entire sideslope area during the period when water is being drawn down. This is not the case, however, since the water level will decline in the BMP. The MIDS calculator assumes a linear drop in water level and thus divides the right hand term in the above equation by 2.

Volume credit for media storage capacity below the underdrain (V_U) is accounted for only if the underdrain is elevated above the native soils. Volume credit for media storage capacity below the underdrain is given by

$V_U = (n-FC)\ D_U\ (A_U + A_B)/2$

where

A_B = surface area at the bottom of the media (square feet);
n = media porosity (cubic feet per cubic foot);
FC is the field capacity of the soil, in cubic feet per cubic foot; and
D_U = the depth of media below the underdrain (feet).

This is an instantaneous volume. This will somewhat overestimate actual storage when the majority of water is being captured by the underdrains. This equation assumes water between the soil porosity and field capacity will infiltrate into the underlying soil.

The volume of water lost through ET is assumed to be the smaller of two calculated values: potential ET and measured ET. Potential ET (ET_{pot}) is equal to the amount of water stored in the basin between field capacity and the wilting point. Measured ET (ET_{mea}) is the amount of water lost to ET as measured using available data and is assumed to be 0.2 inches/day. ET_{mea} is converted to ET by multiplying by a factor of 0.5. ET is considered to occur over a period equal to the drawdown time of the basin. Volume credit for evapotranspiration is given by the lesser of

$ET_{mea} = (0.2/12)\ A\ 0.5\ t$ $ET_{pot} = D\ A\ C_S$

where

t = time over which ET is occurring (days);
D = depth being considered (feet);
A = area being considered (square feet); and
C_S = soil water available for ET, generally assumed to be the water between field capacity and wilting point.

ET is likely to be greater if one or more trees is planted in the biofiltration basin. Planting a tree in a biofiltration system is HIGHLY RECOMMENDED. The MIDS calculator increases the above ET credit by a factor of 3 when a tree is planted in the bioretention basin.

Provided soil water content is greater than the wilting point, ET will continually occur during the non-frozen period. However, because the above volume calculations are event based, t will be equal to the time between rain events. In the MIDS calculator, a value of 3 days is used because this is the average number of days between precipitation events. ET will occur over the entire media depth. D may therefore be set equal to the media depth (D_M). In this case, the value for A would be the average area through the entire depth of the media. The MIDS calculator limits ET to the area above the underdrain. If infiltration is being computed through the bottom and sidewalls of the basin, then C_S would be field capacity minus the wilting point of soils (cubic feet per cubic foot) since water above the field capacity would infiltrate (or go to an underdrain).

The volume of water passing through underdrains can be determined by subtracting the volume loss (V) from the volume of water instantaneously captured by the BMP. No volume reduction credit is given for filtered stormwater that exits through the underdrain, but the volume of filtered water can be used in the calculation of pollutant removal credits through filtration.

The volume reduction credit (V) can be converted to an annual volume if desired. This conversion can be generated using the MIDS calculator or other appropriate modeling techniques. The MIDS calculator obtains the percentage annual volume reduction through performance curves developed from multiple modeling scenarios using the volume reduction capacity for biofiltration, the infiltration rate of the underlying soils, and the contributing watershed size and imperviousness.

Total suspended solids credit calculations

TSS reduction credits correspond with volume reduction through infiltration and filtration of water captured by the biofiltration basin and are given by

$M_{TSS} = M_{TSS_i} + M_{TSS_f}$

where

M_{TSS} = TSS removal (pounds);
M_{TSS_i} = TSS removal from infiltrated water (pounds); and
M_{TSS_f} = TSS removal from filtered water (pounds).

Pollutant removal for infiltrated water is assumed to be 100 percent. The event-based mass of pollutant removed through infiltration, in pounds, is given by

- biofiltration - $M_{TSS_i} = 0.0000624\ (V_{inf_b} + V_{inf_s} + V_U)\ EMC_{TSS}$
- bioinfiltration - $M_{TSS_i} = 0.0000624\ V_{WQ}\ EMC_{TSS}$

where

EMC_{TSS} is the event mean TSS concentration in runoff water entering the BMP (milligrams per liter).

The EMC_{TSS} entering the BMP is a function of the contributing land use and treatment by upstream tributary BMPs. For more information on EMC values for TSS, link here or here. If there is no underdrain, the water quality volume (V_{WQ}) is used in this calculation.

Removal for the filtered portion is less than 100 percent. The event-based mass of pollutant removed through filtration, in pounds, is given by

$M_{TSS_f} = 0.0000624\ (V_{total} - (V_{inf_b} + V_{inf_s} + V_U))\ EMC_{TSS}\ R_{TSS}$

where

V_{total} is the total volume of water captured by the BMP (cubic feet); and
R_{TSS} is the TSS pollutant removal percentage for filtered runoff.

The Stormwater Manual provides a recommended value for R_{TSS} of 0.85 (85 percent) removal for filtered water, while the MIDS calculator provides a value of 0.65 (65 percent). Alternate justified percentages for TSS removal can be used if proven to be applicable to the BMP design.

The above calculations may be applied on an event or annual basis and are given by

$M_{TSS_f} = 2.72\ F\ V_{F_{annual}}\ EMC_{TSS}\ R_{TSS}$

where

F is the fraction of annual volume filtered through the BMP; and
V_{annual} is the annual volume treated by the BMP, in acre-feet.

Phosphorus credit calculations

Total phosphorus (TP) reduction credits correspond with volume reduction through infiltration and filtration of water captured by the biofiltration basin and are given by

$M_{TP} = M_{TP_i} + M_{TP_f}$

where

- M_{TP} = TP removal (pounds);
- M_{TP_i} = TP removal from infiltrated water (pounds); and
- M_{TP_f} = TP removal from filtered water (pounds).

Pollutant removal for infiltrated water is assumed to be 100 percent. The mass of pollutant removed through infiltration, in pounds, is given by

- biofiltration - $M_{TP_i} = 0.0000624\ (V_{inf_b} + V_{inf_s} + V_U)\ EMC_{TP}$
- bioinfiltration - $M_{TP_i} = 0.0000624\ V_{WQ} \ EMC_{TP}$

where

- EMC_{TP} is the event mean TP concentration in runoff water entering the BMP (milligrams per liter).

The EMC_{TP} entering the BMP is a function of the contributing land use and treatment by upstream tributary BMPs.

The filtration credit for TP in bioretention with underdrains assumes removal rates based on the soil media mix used and the presence or absence of amendments. Soil mixes with more than 30 mg/kg phosphorus (P) content are likely to leach phosphorus

and do not qualify for a water quality credit. If the soil phosphorus concentration is less than 30 mg/kg, the mass of phosphorus removed through filtration, in pounds, is given by

$M_{TP_f} = 0.0000624\ (V_{total} - (V_{inf_b} + V_{inf_s} + V_U))\ EMC_{TP}\ R_{TP}$

> **Information:** Soil mixes C and D are assumed to contain less than 30 mg/kg of phosphorus and therefore do not require testing

Again, assuming the phosphorus content in the media is less than 30 milligrams per kilogram, the removal efficiency (R_{TP}) provided in the Stormwater Manual is a function of the fraction of phosphorus that is in particulate or dissolved form, the depth of the media, and the presence or absence of soil amendments. For the purpose of calculating credits it can be assumed that TP in storm water runoff consists of 55 percent particulate phosphorus (PP) and 45 percent dissolved phosphorus (DP). The removal efficiency for particulate phosphorus is 80 percent. The removal efficiency for dissolved phosphorus is 20 percent if the media depth is 2 feet or greater. The efficiency decreases by 1 percent for each 0.1 foot decrease in media thickness below 2 feet. If a soil amendment is added to the BMP design, an additional 40 percent credit is applied to dissolved phosphorus. Thus, the overall removal efficiency, (R_{TP}), expressed as a percent removal of total phosphorus, is given by

$R_{TP} = (0.8 * 0.55) + (0.45 * ((0.2 * (D_{MU_{max=2}})/2) + 0.40_{if amendment is used})) * 100$

where

- the first term on the right side of the equation represents the removal of particulate phosphorus;
- the second term on the right side of the equation represents the removal of dissolved phosphorus; and
- $D_{MU_{max=2}}$ = the media depth above the underdrain, up to a maximum of 2 feet.

Example calculations for TSS and P

Three examples are included based on the extent of infiltration occurring in the BMP. For each of these examples, assume 2.75 acre-feet of water is delivered to a bioretention BMP from 1 acre of impervious surface, the TSS concentration in runoff is 54.5 milligrams per liter, and the total phosphorus concentration is 0.30 milligrams per liter.

Example 1: Bioinfiltration (no underdrain)
Assume the bioinfiltration practice is designed to capture 90 percent of annual runoff, or 2.475 acre-feet. Multiply this by the

concentration (0.3 or 54.5), a conversion factor of 0.0000624 to convert into pounds, and 43560 square feet to convert to cubic feet.

TSS: (0.9*2.75)(54.5)(0.0000624)(43560) = 366.6 pounds
P: (0.9*2.75)(0.3)(0.0000624)(43560) = 2.02 pounds

Example 2: Biofiltration with lined sides and bottom (i.e. no infiltration)
Assume the bioinfiltration practice is designed to capture 90 percent of annual runoff, or 2.475 acre-feet. Assume 1 foot of media, Mix C, above the underdrain and an iron amendment is added. For TSS, the removal efficiency is 85 percent for the water that is captured by the BMP. Since media mix C is used, phosphorus will be removed by the BMP. Calculations must be made for particulate (PP) and dissolved phosphorus (DP). PP accounts for 55 percent of the total phosphorus (TP) and DP for 45 percent of the TP. The removal efficiency for PP is 0.80 (80%) for the water captured by the BMP. For DP, the removal efficiency is 0.20 (20 percent) times the media depth divided by 2 (1/2 or 0.5), plus 0.40 (40 percent, which accounts for the amendment).

TSS: (0.85*0.9*2.75)(54.5)(0.0000624)(43560) = 311.6 pounds
P

PP: (0.55*0.8*0.9*2.75)(0.3)(0.0000624)(43560) = 0.888 pounds
DP: ((0.2*0.5*+0.4)(0.45)(2.75)(43560)(0.3)(0.0000624)) = 0.454 pounds
TP: (0.888+0.454) = 1.342 pounds

Example 3: Biofiltration with unlined sides and bottom (i.e. some infiltration occurs)
To make this calculation, we need to know the percent of water that infiltrates and the percent that is captured by the underdrain. Note the volume infiltrated will need to be calculated using the methodology described above. To simplify the calculations in this example, assume 10 percent of the captured water infiltrates, while the remaining water goes to the underdrain.

TSS

Infiltrated: (0.9)(0.1)(43560)(2.75)(54.5)(0.0000624) = 36.7 pounds. Note this is 10 percent of the volume calculated in Example 1.
Filtered (underdrain): (0.85)(0.9)(0.9)(43560)(2.75)(54.5)(0.0000624) = 280.5 pounds. Note this is 90 percent of the TSS calculated in Example 2.
Total: 317.2 pounds

P

Infiltrated: (0.9)(0.1)(43560)(2.75)(0.3)(0.0000624) = 0.202 pounds. Note this is 10 percent of the volume calculated in Example 1.
Filtered (underdrain): This calculation is the same as for Example 2, corrected for only 90 percent of the volume being treated by filtration. (1.342)(0.9) = 1.208 pounds
Total: 1.410 pounds

Methods for calculating credits

This section provides specific information on generating and calculating credits from bioretention BMPS for volume, Total Suspended Solids (TSS) and Total Phosphorus (TP). Stormwater runoff volume and pollution reductions ("credits") may be calculated using one of the following methods:

1. Quantifying volume and pollution reductions based on accepted hydrologic models
2. The Simple Method and MPCA Estimator
3. MIDS Calculator
4. Quantifying volume and pollution reductions based on values reported in literature
5. Quantifying volume and pollution reductions based on field monitoring

Credits based on models

Warning: The model selected depends on your objectives. For compliance with the Construction Stormwater permit, the model must be based on the assumption that an instantaneous volume is captured by the BMP.

Users may opt to use a water quality model or calculator to compute volume, TSS and/or TP pollutant removal for the purpose of determining credits for bioretention. The available models described below are commonly used by water resource professionals, but are not explicitly endorsed or required by the Minnesota Pollution Control Agency. Furthermore, many of the models listed below cannot be used to determine compliance with the Construction Stormwater General permit since the permit requires the water quality volume to be calculated as an instantaneous volume.

Use of models or calculators for the purpose of computing pollutant removal credits should be supported by detailed documentation, including:

- Model name and version
- Date of analysis
- Person or organization conducting analysis
- Detailed summary of input data
- Calibration and verification information
- Detailed summary of output data

The following table lists water quantity and water quality models that are commonly used by water resource professionals to predict the hydrologic, hydraulic, and/or pollutant removal capabilities of a single or multiple stormwater BMPs. The table can be used to guide a user in selecting the most appropriate model for computing volume, TSS, and/or TP removal for bioretention BMPs. In using this table to identify models appropriate for bioretention, use the sort arrow on the table to select Infiltrator BMPs or Filter BMPs, depending on the type of bioretention BMP and the terminology used in the model.

Comparison of stormwater models and calculators. Additional information and descriptions for some of the models listed in this table can be found at this link. Note that the Construction Stormwater General Permit requires the water quality volume to be calculated as an instantaneous volume, meaning several of these models cannot be used to determine compliance with the permit.
Link to this table
Access this table as a Microsoft Word document: File:Stormwater Model and Calculator Comparisons table.docx.

Model name	BMP Category						Assess TP removal?	Assess TSS removal?	Assess volume reduction?	Comments
	Constructed basin BMPs	Filter BMPs	Infiltrator BMPs	Swale or strip BMPs	Reuse	Manu-factured devices				
Center for Neighborhood Technology Green Values National Stormwater Management Calculator	X	X	X		X		No	No	Yes	Does not compute volume reduction for some BMPs, including cisterns and tree trenches.

CivilStorm							Yes	Yes	Yes	CivilStorm has an engineering library with many different types of BMPs to choose from. This list changes as new information becomes available.
EPA National Stormwater Calculator	X		X		X		No	No	Yes	Primary purpose is to assess reductions in stormwater volume.
EPA SWMM	X		X		X		Yes	Yes	Yes	User defines parameter that can be used to simulate generalized constituents.
HydroCAD	X		X	X			No	No	Yes	Will assess hydraulics, volumes, and pollutant loading, but

										not pollutant reduction.
infoSWMM	X		X		X		Yes	Yes	Yes	User defines parameter that can be used to simulate generalized constituents.
infoWorks ICM	X	X	X	X			Yes	Yes	Yes	
i-Tree-Hydro			X				No	No	Yes	Includes simple calculator for rain gardens.
i-Tree-Streets							No	No	Yes	Computes volume reduction for trees, only.
LSPC	X		X	X			Yes	Yes	Yes	Though developed for HSPF, the USEPA BMP Web Toolkit can be used with LSPC to model structural BMPs such as detention basins, or infiltration

										BMPs that represent source control facilities, which capture runoff from small impervious areas (e.g., parking lots or rooftops).
MapShed	X	X	X	X			Yes	Yes	Yes	Region-specific input data not available for Minnesota but user can create this data for any region.
MCWD/MWMO Stormwater Reuse Calculator					X		Yes	No	Yes	Computes storage volume for stormwater reuse systems
Metropolitan Council Stormwater Reuse Guide Excel Spreadsheet					X		No	No	Yes	Computes storage volume for stormwater reuse systems. Uses

										30-year precipitation data specific to Twin Cites region of Minnesota.
MIDS Calculator	X	X	X	X	X	X	Yes	Yes	Yes	Includes user-defined feature that can be used for manufactured devices and other BMPs.
MIKE URBAN (SWMM or MOUSE)	X		X		X		Yes	Yes	Yes	User defines parameter that can be used to simulate generalized constituents.
P8	X		X	X		X	Yes	Yes	Yes	
PCSWMM	X		X		X		Yes	Yes	Yes	User defines parameter that can be used to simulate generalized constituents.
PLOAD	X	X	X	X		X	Yes	Yes	No	User-defined practices with

										user-specified removal percentages.
PondNet	X						Yes	No	Yes	Flow and phosphorus routing in pond networks.
PondPack	X		[				No	No	Yes	PondPack can calculate first-flush volume, but does not model pollutants. It can be used to calculate pond infiltration.
RECARGA			X				No	No	Yes	
SELECT	X	X	X	X		X	Yes	Yes	Yes	User defines parameter that can be used to simulate generalized constituents.
SHSAM						X	No	Yes	No	Several flow-through structures including standard

										sumps, and proprietary systems such as CDS, Stormceptors, and Vortechs systems
SUSTAIN	X	X	X	X	X		Yes	Yes	Yes	Categorizes BMPs into Point BMPs, Linear BMPs, and Area BMPs
SWAT	X	X	X				Yes	Yes	Yes	Model offers many agricultural BMPs and practices, but limited urban BMPs at this time.
Virginia Runoff Reduction Method	X	X	X	X	X	X	Yes	No	Yes	Users input Event Mean Concentration (EMC) pollutant removal percentages for manufactured devices.
WARMF	X	X					Yes	Yes	Yes	Includes

										agriculture BMP assessment tools. Compatible with USEPA Basins
WinHSPF	X		X	X			Yes	Yes	Yes	USEPA BMP Web Toolkit available to assist with implementing structural BMPs such as detention basins, or infiltration BMPs that represent source control facilities, which capture runoff from small impervious areas (e.g., parking lots or rooftops).
WinSLAMM	X	X	X	X			Yes	Yes	Yes	
XPSWMM	X		X		X		Yes	Yes	Yes	User defines parameter

										that can be used to simulate generalized constituents.

The Simple Method and MPCA Estimator

The Simple Method is a technique used for estimating storm pollutant export delivered from urban development sites. Pollutant loads are estimated as the product of mean pollutant concentrations and runoff depths over specified periods of time (usually annual or seasonal). The method was developed to provide an easy yet reasonably accurate means of predicting the change in pollutant loadings in response to development. Ohrel (2000) states: "In general, the Simple Method is most appropriate for small watersheds (<640 acres) and when quick and reasonable stormwater pollutant load estimates are required". Rainfall data, land use (runoff coefficients), land area, and pollutant concentration are needed to use the Simple Method. For more information on the Simple Method, see The Simple method to Calculate Urban Stormwater Loads or The Simple Method for estimating phosphorus export.

Some simple stormwater calculators utilize the Simple Method (STEPL, Watershed Treatment Model). The MPCA developed a simple calculator for estimating load reductions for TSS, total phosphorus, and bacteria. Called the **MPCA Estimator**, this tool was developed specifically for complying with the MS4 General Permit TMDL annual reporting requirement. The MPCA Estimator provides default values for pollutant concentration, runoff coefficients for different land uses, and precipitation, although the user can modify these and is encouraged to do so when local data exist. The user is required to enter area for different land uses and area treated by BMPs within each of the land uses. BMPs include infiltrators (e.g. bioinfiltration, infiltration basin, tree trench, permeable pavement, etc.), filters (biofiltration, sand filter, green roof), constructed ponds and wetlands, and swales/filters. The MPCA Estimator includes standard removal efficiencies for these BMPs, but the user can modify those values if better data are available. Output from the calculator is given as a load reduction (percent, mass, or number of bacteria) from the original estimated load.

Warning: The MPCA Estimator should not be used for modeling a stormwater system or selecting BMPs.

Because the MPCA Estimator does not consider BMPs in series, makes simplifying assumptions about runoff and pollutant removal processes, and uses generalized default information, it should only be used for estimating pollutant reductions from an estimated load. It is not intended as a decision-making tool.

Download MPCA Estimator here: File:MPCA Estimator.xlsx

A quick guide for the estimator is available Quick Guide: MPCA Estimator tab.

MIDS Calculator

Download the MIDS Calculator

The Minimal Impact Design Standards (MIDS) best management practice (BMP) calculator is a tool used to determine stormwater runoff volume and pollutant reduction capabilities of various low impact development (LID) BMPs. The MIDS calculator estimates the stormwater runoff volume reductions for various BMPs and annual pollutant load reductions for total phosphorus (including a breakdown between particulate and dissolved phosphorus) and total suspended solids (TSS). The calculator was intended for use on individual development sites, though capable modelers could modify its use for larger applications.

The MIDS calculator is designed in Microsoft Excel with a graphical user interface (GUI), packaged as a windows application, used to organize input parameters. The Excel spreadsheet conducts the calculations and stores parameters, while the GUI provides a platform that allows the user to enter data and presents results in a user-friendly manner.

Detailed guidance has been developed for all BMPs in the calculator, including biofiltration and bioinfiltration. An overview of individual input parameters and workflows is presented in the MIDS Calculator User Documentation.

Credits based on reported literature values

A simplified approach to computing a credit would be to apply a reduction value found in literature to the pollutant mass load or concentration (EMC) of the bioretention device. Concentration reductions resulting from treatment can be converted to mass reductions if the volume of stormwater treated is known.

Designers may use the pollutant reduction values reported in this manual or may research values from other databases and published literature. Designers who opt for this approach should

- select the median value from pollutant reduction databases that report a range of reductions, such as from the International BMP Database;
- select a pollutant removal reduction from literature that studied a bioretention device with site characteristics and climate similar to the device being considered for credits;
- review the article to determine that the design principles of the studied bioretention are close to the design recommendations for Minnesota, as described in this manual and/or by a local permitting agency; and
- give preference to literature that has been published in a peer-reviewed publication.

The following references summarize pollutant reduction values from multiple studies or sources that could be used to determine credits. Users should note that there is a wide range of monitored pollutant removal effectiveness in the literature. Before selecting a literature value, users should compare the characteristics of the monitored site in the literature against the characteristics of the proposed bioretention device, considering such conditions as watershed characteristics, bioretention sizing, soil infiltration rates, and climate factors.

- International Stormwater Best Management Practices (BMP) Database Pollutant Category Summary Statistical Addendum: TSS, Bacteria, Nutrients, and Metals
  - Compilation of BMP performance studies published through 2011
  - Provides values for TSS, Bacteria, Nutrients, and Metals
  - Applicable to grass strips, bioretention, bioswales, detention basins, green roofs, manufactured devices, media filters, porous pavements, wetland basins, and wetland channels
- Effectiveness Evaluation of Best Management Practices for Stormwater Management in Portland, Oregon
  - Appendix M contains Excel spreadsheet of structural and non-structural BMP performance evaluations
  - Provides values for sediment, nutrients, pathogens, metals, quantity, air purification, carbon sequestration, flood storage, avian habitat, aquatics habitat and aesthetics
  - Applicable to filters, wet ponds, porous pavements, soakage trenches, flow-through stormwater planters, infiltration stormwater planters, vegetated infiltration basins, swales, and treatment wetlands
- The Illinois Green Infrastructure Study
  - Figure ES-1 summarizes BMP effectiveness
  - Provides values for TN, TSS, peak flows / runoff volumes
  - Applicable to permeable pavements, constructed wetlands, infiltration, detention, filtration, and green roofs
- New Hampshire Stormwater Manual
  - Volume 2, Appendix B summarizes BMP effectiveness

- Provides values for TSS, TN, and TP removal
- Applicable to basins and wetlands, stormwater wetlands, infiltration practices, filtering practices, treatment swales, vegetated buffers, and pre-treatment practices

- Design Guidelines for Stormwater Bioretention Facilities. University of Wisconsin, Madison
  - Table 2-1 summarizes typical removal rates
  - Provides values for TSS, metals, TP, TKN, ammonium, organics, and bacteria
  - Applicable for bioretention
- BMP Performance Analysis. Prepared for US EPA Region 1, Boston MA.
  - Appendix B provides pollutant removal performance curves
  - Provides values for TP, TSS, and zinc
  - Pollutant removal broken down according to land use
  - Applicable to infiltration trench, infiltration basin, bioretention, grass swale, wet pond, and porous pavement
- Weiss, P.T., J.S. Gulliver and A.J. Erickson. 2005. The Cost and Effectiveness of Stormwater Management Practices: Final Report
  - Table 8 and Appendix B provides pollutant removal efficiencies for TSS and P
  - Applicable to wet basins, stormwater wetlands, bioretention filter, sand filter, infiltration trench, and filter strips/grass swales

Credits based on field monitoring

Field monitoring may be used to calculate stormwater credits in lieu of desktop calculations or models/calculators as described. Careful planning is HIGHLY RECOMMENDED before commencing a program to monitor the performance of a BMP. The general steps involved in planning and implementing BMP monitoring include the following.

1. Establish the objectives and goals of the monitoring.
   a. Which pollutants will be measured?
   b. Will the monitoring study the performance of a single BMP or multiple BMPs?
   c. Are there any variables that will affect the BMP performance? Variables could include design approaches, maintenance activities, rainfall events, rainfall intensity, etc.
   d. Will the results be compared to other BMP performance studies?
   e. What should be the duration of the monitoring period? Is there a need to look at the annual performance vs the performance during a single rain event? Is there a need to assess the seasonal variation of BMP performance?
2. Plan the field activities. Field considerations include:

a. Equipment selection and placement
b. Sampling protocols including selection, storage, delivery to the laboratory
c. Laboratory services
d. Health and Safety plans for field personnel
e. Record keeping protocols and forms
f. Quality control and quality assurance protocols

3. Execute the field monitoring
4. Analyze the results

The following guidance manuals have been developed to assist BMP owners and operators on how to plan and implement BMP performance monitoring.

Urban Stormwater BMP Performance Monitoring

Geosyntec Consultants and Wright Water Engineers prepared this guide in 2009 with support from the USEPA, Water Environment Research Foundation, Federal Highway Administration, and the Environment and Water Resource Institute of the American Society of Civil Engineers. This guide was developed to improve and standardize the protocols for all BMP monitoring and to provide additional guidance for Low Impact Development (LID) BMP monitoring. Highlighted chapters in this manual include:

- Chapter 2: Designing the Program
- Chapters 3 & 4: Methods and Equipment
- Chapters 5 & 6: Implementation, Data Management, Evaluation and Reporting
- Chapter 7: BMP Performance Analysis
- Chapters 8, 9, & 10: LID Monitoring

Evaluation of Best Management Practices for Highway Runoff Control (NCHRP Report 565)

AASHTO (American Association of State Highway and Transportation Officials) and the FHWA (Federal Highway Administration) sponsored this 2006 research report, which was authored by Oregon State University, Geosyntec Consultants, the University of Florida, and the Low Impact Development Center. The primary purpose of this report is to advise on the selection and design of BMPs that are best suited for highway runoff. The document includes the following chapters on performance monitoring that may be a useful reference for BMP performance monitoring, especially for the performance assessment of a highway BMP:

- Chapter 4: Stormwater Characterization

- 4.2: General Characteristics and Pollutant Sources
- 4.3: Sources of Stormwater Quality data

- Chapter 8: Performance Evaluation
  - 8.1: Methodology Options
  - 8.5: Evaluation of Quality Performance for Individual BMPs
  - 8.6: Overall Hydrologic and Water Quality Performance Evaluation
- Chapter 10: Hydrologic Evaluation
  - 10.5: Performance Verification and Design Optimization

Investigation into the Feasibility of a National Testing and Evaluation Program for Stormwater Products and Practices.

In 2014 the Water Environment Federation released this White Paper that investigates the feasibility of a national program for the testing of stormwater products and practices. The information contained in this White Paper would be of use to those considering the monitoring of a manufactured BMP. The report does not include any specific guidance on the monitoring of a BMP, but it does include a summary of the existing technical evaluation programs that could be consulted for testing results for specific products (see Table 1 on page 8).

Caltrans Stormwater Monitoring Guidance Manual (Document No. CTSW-OT-13-999.43.01)

The most current version of this manual was released by the State of California, Department of Transportation in November 2013. As with the other monitoring manuals described, this manual does include guidance on planning a stormwater monitoring program. However, this manual is among the most thorough for field activities. Relevant chapters include:

- Chapter 4: Monitoring Methods and Equipment
- Chapter 5: Analytical Methods and Laboratory Selection
- Chapter 6: Monitoring Site Selection
- Chapter 8: Equipment Installation and Maintenance
- Chapter 10: Pre-Storm Preparation
- Chapter 11: Sample Collection and Handling
- Chapter 12: Quality Assurance / Quality Control
- Chapter 13: Laboratory Reports and Data Review
- Chapter 15: Gross Solids Monitoring

Optimizing Stormwater Treatment Practices: A Handbook of Assessment and Maintenance

This online manual was developed in 2010 by Andrew Erickson, Peter Weiss, and John Gulliver from the University of Minnesota and St. Anthony Falls Hydraulic Laboratory with funding provided by the Minnesota Pollution Control Agency. The manual advises on a four-level process to assess the performance of a Best Management Practice, involving:

- Level 1: Visual Inspection
- Level 2: Capacity Testing
- Level 3: Synthetic Runoff Testing
- Level 4: Monitoring
- Level 1 activities do not produce numerical performance data that could be used to obtain a stormwater management credit. BMP owners and operators who are interested in using data obtained from Levels 2 and 3 should consult with the MPCA or other regulatory agency to determine if the results are appropriate for credit calculations. Level 4, Monitoring, is the method most frequently used for assessment of the performance of a BMP.

Use these links to obtain detailed information on the following topics related to BMP performance monitoring:

- Water Budget Measurement
- Sampling Methods
- Analysis of Water and Soils
- Data Analysis for Monitoring

Other pollutants

In addition to TSS and phosphorus, bioretention BMPs can reduce loading of other pollutants. According to the International Stormwater Database, studies have shown that bioretention BMPs are effective at reducing concentrations of pollutants, including metals, and bacteria. A compilation of the pollutant removal capabilities from a review of literature are summarized below.

Relative pollutant reduction from bioretention systems for metals, nitrogen, bacteria, and organics.
Link to this table

Pollutant	Constituent	Treatment capabilities[1]
Metals[2]	Cadmium, Chromium, Copper, Zinc, Lead	High

Nitrogen[2]	Total nitrogen, Total Kjeldahl nitrogen	Low/medium
Bacteria[2]	Fecal coliform, e. coli	High
Organics	Petroleum hydrocarbons[3], Oil/grease[4]	High

[1] Low: < 30%; Medium: 30 to 65%; High: >65%

[2] International Stormwater Database, (2012)

[3] LeFevre et al., (2012)

[4] Hsieh and Davis (2005).

References and suggested reading

- Brown, Robert A., and William F. Hunt III. 2010. *Impacts of media depth on effluent water quality and hydrologic performance of undersized bioretention cells.* Journal of Irrigation and Drainage Engineering 137, no. 3: 132-143.
- Brown, R. A., and W. F. Hunt. 2011. *Underdrain configuration to enhance bioretention exfiltration to reduce pollutant loads.* Journal of Environmental Engineering 137, no. 11: 1082-1091.
- Bureau of Environmental Services. 2006. Effectiveness Evaluation of Best Management Practices for Stormwater Management in Portland. Oregon. Bureau of Environmental Services, Portland, Oregon.
- California Stormwater Quality Association. 2003. California Stormwater BMP Handbook-New Development and Redevelopment. California Stormwater Quality Association, Menlo Park, CA.
- Chris, Denich, Bradford Andrea, and Drake Jennifer. 2013. *Bioretention: assessing effects of winter salt and aggregate application on plant health, media clogging and effluent quality*. Water Quality Research Journal of Canada. 48(4):387.
- Caltrans. 2004. BMP Retrofit Pilot Program Final Report. Report No. CTSW-RT-01-050. Division of Environmental Analysis. California Dept. of Transportation, Sacramento, CA.
- Caltrans. 2013. Caltrans Stormwater Monitoring Guidance Manual. Document No. CTSW-OY-13-999.43.01.
- CDM Smith. 2012. Omaha Regional Stormwater Design Manual. Chapter 8 Stormwater Best Management Practices. Kansas City, MO.
- Davis, Allen P., Mohammad Shokouhian, Himanshu Sharma, and Christie Minami. 2001. *Laboratory study of biological retention for urban stormwater management.* Water Environment Research, 73, no. 1:5-14.

- Davis, Allen P., Mohammad Shokouhian, Himanshu Sharma, and Christie Minami. 2006. *Water quality improvement through bioretention media: Nitrogen and phosphorus removal*. Water Environment Research 78, no. 3: 284-293.
- Davis, Allen P., Mohammad Shokouhian, Himanshu Sharma, Christie Minami, and Derek Winogradoff. 2003. *Water quality improvement through bioretention: Lead, copper, and zinc removal*. Water Environment Research 75, no. 1: 73-82.
- DiBlasi, Catherine J., Houng Li, Allen P. Davis, and Upal Ghosh. 2008. *Removal and fate of polycyclic aromatic hydrocarbon pollutants in an urban stormwater bioretention facility*. Environmental science & technology 43, no. 2: 494-502.
- Dorman, M. E., H. Hartigan, F. Johnson, and B. Maestri. 1988. Retention, detention, and overland flow for pollutant removal from highway stormwater runoff: interim guidelines for management measures. Final report, September 1985-June 1987. No. PB-89-133292/XAB. Versar, Inc., Springfield, VA (USA).
- Geosyntec Consultants and Wright Water Engineers. 2012. Urban Stormwater BMP Performance Monitoring. Prepared under Support from U.S. Environmental Protection Agency, Water Environment Research Foundation, Federal Highway Administration, Environmental and Water Resource Institute of the American Society of Civil Engineers.
- Gulliver, J. S., A. J. Erickson, and P.T. Weiss. 2010. Stormwater treatment: Assessment and maintenance. University of Minnesota, St. Anthony Falls Laboratory. Minneapolis, MN.
- Hathaway, J. M., W. F. Hunt, and S. Jadlocki. 2009. *Indicator bacteria removal in storm-water best management practices in Charlotte, North Carolina*. Journal of Environmental Engineering 135, no. 12: 1275-1285.
- Hong, Eunyoung, Eric A. Seagren, and Allen P. Davis. 2006. *Sustainable oil and grease removal from synthetic stormwater runoff using bench-scale bioretention studies*. Water Environment Research 78, no. 2: 141-155.
- Hsieh, Chi-hsu, and Allen P. Davis. 2005. *Evaluation and optimization of bioretention media for treatment of urban storm water runoff*. Journal of Environmental Engineering 131, no. 11: 1521-1531.
- Hunt, W. F., A. R. Jarrett, J. T. Smith, and L. J. Sharkey. 2006. *Evaluating bioretention hydrology and nutrient removal at three field sites in North Carolina*. Journal of Irrigation and Drainage Engineering 132, no. 6: 600-608.
- Jaffe, et. al. 2010. The Illinois Green Infrastructure Study. Prepared by the University of Illinois at Chicago, Chicago Metropolitan Agency for Planning. Center for Neighborhood Technology, Illinois-Indiana Sea Grant College Program.
- Jurries, Dennis. 2003. Biofilters (Bioswales, Vegetative Buffers, & Constructed Wetlands) for Storm Water Discharge Pollution Removal. Quality, State of Oregon, Department of Environmental Quality (Ed.).
- Lefevre G.H., Hozalski R.M., Novak P. 2012. *The role of biodegradation in limiting the accumulation of petroleum hydrocarbons in raingarden soil*. Water Res. 46(20):6753-62.
- Leisenring, M., J. Clary, and P. Hobson. 2012. *International Stormwater Best Management Practices (BMP) Database Pollutant Category Summary Statistical Addendum: TSS, Bacteria, Nutrients, and Metals*. July: 1-31.
- Li, Houng, and Allen P. Davis. 2009. *Water quality improvement through reductions of pollutant loads using bioretention*. Journal of Environmental Engineering 135, no. 8: 567-576.

- Komlos, John, and Robert G. Traver. 2012. *Long-term orthophosphate removal in a field-scale storm-water bioinfiltration rain garden*. Journal of Environmental Engineering 138, no. 10: 991-998.
- Mid-America Regional Council, and American Public Works Association. 2012. Manual of best management practices for stormwater quality.
- New Hampshire Department of Environmental Services. 2008. New Hampshire Stormwater Manual. Volume 2 Appendix B. Concord, NH.
- North Carolina Department of Environment and Natural Resources. 2007. Stormwater Best Management Practices Manual. North Carolina Department of Environment and Natural Resources, Raleigh, North Carolina.
- Passeport, Elodie, William F. Hunt, Daniel E. Line, Ryan A. Smith, and Robert A. Brown. 2009. *Field study of the ability of two grassed bioretention cells to reduce storm-water runoff pollution*. Journal of Irrigation and Drainage Engineering 135, no. 4: 505-510.
- Ohrel, R. 2000. Simple and Complex Stormwater Pollutant Load Models Compared: The Practice of Watershed Protection. Center for Watershed Protection, Ellicott City, MD. Pages 60-63
- Oregon State University Transportation Officials. Dept. of Civil, Environmental Engineering, University of Florida. Dept. of Environmental Engineering Sciences, GeoSyntec Consultants, and Low Impact Development Center, Inc. 2006. Evaluation of Best Management Practices for Highway Runoff Control. No. 565. Transportation Research Board.
- Schueler, T.R., Kumble, P.A., and Heraty, M.A. 1992. *A Current Assessment of Urban Best Management Practices: Techniques for Reducing Non-Point Source Pollution in the Coastal Zone*. Metropolitan Washington Council of Governments, Washington, D.C.
- TetraTech. 2008. BMP Performance Analysis. Prepared for US EPA Region 1, Boston, MA.
- Torres, Camilo. 2010. Characterization and Pollutant Loading Estimation for Highway Runoff in Omaha, Nebraska. M.S. Thesis, University of Nebraska, Lincoln.
- United States EPA. 1999. Stormwater technology fact sheet-bioretention. Office of Water, EPA 832-F-99 12.
- University of Wisconsin. 2006. Design Guidelines for Stormwater Bioretention Facilities.
- Water Environment Federation. 2014. Investigation into the Feasibility of a National Testing and Evaluation Program for Stormwater Products and Practices. A White Paper by the National Stormwater Testing and Evaluation of Products and Practices (STEPP) Workgroup Steering Committee.
- WEF, ASCE/EWRI. 2012. *Design of Urban Stormwater Controls*. WEF Manual of Practice No. 23, ASCE/EWRI Manuals and Reports on Engineering Practice No. 87. Prepared by the Design of Urban Stormwater Controls Task Forces of the Water Environment Federation and the American Society of Civil Engineers/Environmental & Water Resources Institute.
- Weiss, Peter T., John S. Gulliver, and Andrew J. Erickson. 2005. The Cost and Effectiveness of Stormwater Management Practices Final Report.. Published by: Minnesota Department of Transportation.
- Wossink, G. A. A., and Bill Hunt. 2003. The economics of structural stormwater BMPs in North Carolina. Water Resources Research Institute of the University of North Carolina.

Related articles

- Bioretention
  - Bioretention terminology (including types of bioretention)
  - Overview for bioretention
  - Design criteria for bioretention
  - Construction specifications for bioretention
  - Operation and maintenance of bioretention
  - Cost-benefit considerations for bioretention
  - Calculating credits for bioretention
  - Soil amendments to enhance phosphorus sorption
  - Summary of permit requirements for bioretention
  - Supporting material for bioretention
  - External resources for bioretention
  - References for bioretention
  - Requirements, recommendations and information for using bioretention with no underdrain BMPs in the MIDS calculator
  - Requirements, recommendations and information for using bioretention with an underdrain BMPs in the MIDS calculator
- Calculating credits
  - Calculating credits for bioretention
  - Calculating credits for infiltration basin
  - Calculating credits for infiltration trench
  - Calculating credits for permeable pavement
  - Calculating credits for green roofs
  - Calculating credits for sand filter
  - Calculating credits for stormwater ponds
  - Calculating credits for stormwater wetlands
  - Calculating credits for iron enhanced sand filter
  - Calculating credits for swale
  - Calculating credits for tree trenches and tree boxes
  - Calculating credits for stormwater and rainwater harvest and use/reuse

Green infrastructure benefits of bioretention

This site is currently undergoing revision. For more information, open this link.
This page is in development


Example of a rain garden planted with native vegetation.

Bioretention practices, often called rain gardens, are small vegetated landscape practices designed to filter or infiltrate stormwater runoff. They have a relatively simplistic design that can be incorporated into a wide variety of landscaped areas. Common bioretention opportunities include landscaping islands, cul-de-sacs, parking lot margins, commercial setbacks, open space, rooftop drainage and street-scapes (i.e., between the curb and sidewalk).

Nomenclature and definitions for green infrastructure benefits

There are a wide variety of green infrastructure (GI) benefits identified in the literature and no universal nomenclature or set of definitions. Nomenclature and definitions used in the following discussion are described in detail at the page called Nomenclature and definitions for green infrastructure benefits.

Green Infrastructure benefits of bioretention

Because of their diversity and use of vegetation, bioretention practices provide multiple green infrastructure benefits.

Benefit	Effectiveness	Notes
Water quality	●	Benefits are maximized for bioinfiltration. Biofiltration may export phosphorus if not

- Water quality: Bioretention is an excellent stormwater treatment practice due to the variety of pollutant removal mechanisms, including vegetative filtering, settling, evaporation, infiltration, transpiration, biological and microbiological uptake, and soil adsorption. Bioretention can be designed as an effective infiltration / recharge practice, particularly when parent soils have high permeability (> ~ 0.5 inches per hour). Bioretention designed for infiltration (bioinfiltration) removes 100 percent of pollutants for the portion of runoff water that is infiltrated, although there may be impacts to shallow groundwater. Bioretention designed as filtration (biofiltration) employs engineered media that is effective at removing solids, most metals, and most organic chemicals. Removal of phosphorus depends on the media (link here). Links to water quality information for bioretention - [7]; [8]
- Water quantity and hydrology: Bioretention can be designed as an effective infiltration / recharge practice when parent soils have high permeability. For lower permeability soils an underdrain is typically used and some infiltration and rate control can be achieved.
- Climate resiliency: It is unclear if bioretention provides benefits for climate resiliency. Carbon may be sequestered, particularly if shrubs and trees exist in the practice. Bioretention also provides some reduction in peak flow. Carbon emissions for construction and maintenance may offset carbon benefits (Moore and Hunt, 2013). Winston (2016) provides a detailed analysis of resiliency of bioretention systems based on different design considerations, such as bowl depth and vegetation utilized in the practice.

		designed properly.
Water quantity/supply	◕	Bioinfiltration helps mimic natural hydrology. Some rate control benefit.
Energy savings	○	
Climate resiliency	◔	Provides some rate control. Impacts on carbon sequestration are uncertain.
Air quality	○	
Habitat improvement	◕	Use of perennial vegetation and certain media mixes promote invertebrate communities.
Community livability	◕	Aesthetically pleasing and can be incorporated into a wide range of land use settings.
Health benefits	◔	
Economic savings	◔	Generally provide cost savings vs. conventional practices over the life of the practice.
Macroscale benefits	◑	Individual bioretention practices are typically microscale, but multiple bioretention practices, when incorporated into a landscape design, provide macroscale benefits such as wildlife corridors.
Level of benefit: ○ - none; ◔; - small; ◑ - moderate; ◕ - large; ● - very high		

- Habitat improvement: Properly designed bioretention practices provide good habitat for invertebrates (Kazemi et al., 2009; Mehring et al., 2016). Beneficial effects are improved considerably when multiple bioretention practices exist over a landscape, as opposed to isolated bioretention practices.
- Community livability: Bioretention is an aesthetically pleasing practice that can easily be incorporated into various landscapes. A variety of vegetation can also be used, including perennial plants, shrubs, and trees.
- Health benefits: Green spaces may also improve mental and physical health for residents and reduce crime (Barton and Rogerson, 2017).
- Economic savings: Properly designed and integrated bioretention practices provide life cycle cost savings. Well designed and maintained bioretention practices increase property values.

Design considerations


Bioretention practices can be incorporated into a wide variety of landscapes.

Maximizing specific green infrastructure (GI) benefits of bioretention practices requires design considerations prior to constructing the practice. While site limitations cannot always be overcome, the following recommendations maximize the GI benefit of bioretetnion.

- Water quality
  - Maximize infiltration by designing with the maximum ponded depth that can be infiltrated in 48 hours, up to 1.5 feet (to protect vegetation). Where space allows, surface area can also be increased. Utilize multiple bioretention practices in series. On lower permeability soils where an underdrain is used, raise the underdrain to the maximum extent possible, allowing water stored in the bioretention media below the underdrain to drain in 48 hours. Use an upturned elbow in underdrained systems.
  - For bioinfiltration (bioretention without an underdrain), use a high organic matter media to maximize pollutant removal
  - For biofiltration (bioretention with an underdrain), use a media mix that does not export phosphorus or use an amendment to attenuate phosphorus.
- Water quantity/supply
  - Maximize infiltration
  - Utilize internal water storage

    - Maximize water storage in media
- Climate resiliency
    - To reduce heat island effects, select vegetation that reflects solar energy, absorbs solar energy and releases it slowly, or that maximizes evapotranspiration NYC Mayor's Office of Recovery and Resiliency
    - Oversize bowl depth (storage) to account for increased precipitation. Winston (2016) recommends oversizing by 33-45% for bioretention in northern Ohio. Oversizing can also be accomplished by reducing loading to individual bioretention practices.
    - Establish thicker media depths (Winston (2016) recommends 48 to 102 inches for northern Ohio) to enhance vegetation survival during wet or extended dry periods.
    - Utilize internal water storage
- Habitat
    - Utilize native, perennial vegetation, including shrubs and trees if space allows. For more information, see Minnesota plant lists.
    - Incorporate landscape features, such as form, plant layering, and plant density. For more information on landscape factors, see this presentation by Dr. Steven Rodie (University of Nebraska at Omaha)
    - Maximize leaf/plant litter depth and the number of plant taxa
    - Consider shape and size to create larger interior habitats
    - Evaluate adjacent plant communities for compatibility with proposed bioretention area species. Identify nearby vegetated areas that are dominated by nonnative invasive species.
    - Promote soil (media) that maximizes habitat for invertebrate. This includes adjusting pH, limiting the amount of gravel, and promoting development of organic matter. See Kazemi et al. (2009) for more information.

Caution: Biofiltration practices (bioretention with an underdrain) may export phosphorus. Select an appropriate mix or add amendments that attenuate phosphorus to the design.

- Community livability
    - Choose locations for bioretention that enhance aesthetics
    - Choose vegetation that mimics a native landscape, such as tall grass prairie or mixed woodland.
    - Evaluate the best placement of vegetation within the bioretention area. Place plants at irregular intervals to replicate a natural setting. Trees should be placed on the perimeter of the area to provide shade and shelter from the wind. Trees and shrubs can be sheltered from damaging flows if they are placed away from the path of the incoming runoff. In cold climates, species that are more tolerant to cold winds, such as evergreens, should be placed in windier areas of the site.

- Health benefits
  - Choose locations for bioretention that enhance aesthetics
  - Perennial vegetation, particularly shrubs and trees, provide health beenfits related to filtering air pollutants. See The Health Benefits of Trees (Hamblin, 2014)
- Economic benefits
  - Choose the correct BMP. There is no comprehensive guidance on this, but an important factor in selecting BMPs is cost per unit treatment. This depends on the goal of the project, but examples of costs may be dollars per cubic foot of water treated or per pound of pollutant. Barr Engineering completed a report that provides information on construction costs, maintenance costs, and land requirements for several stormwater BMPs. The report includes references to other useful reports. Information in the report can be used to match the site goals (e.g. infiltration vs. filtration) and site conditions (e.g. large vs. small site) to the most cost-efficient BMP.
  - Factor in all benefits in evaluating the economic value of a BMP or multiple GI practices. For example, appropriate implementation of GI practices can enhance property values. Proper selection of vegetation provides energy savings. Utilizing captured rainwater as an indoor non-potable water source provides savings on energy and water use.
  - Utilize multiple properly placed BMPs that work together. For example, permeable pavement can be integrated with tree trenches and tree boxes to provide an aesthetically pleasing landscape that increases the value of the property while increasing the efficiency of stormwater treatment.


Bioretention practices can be incorporated into street landscapes. These bioretention practices include a variety of plants and are incorporated into a setting that includes mature trees, providing variety and contrast. Image Courtesy of Emmons & Olivier Resources, Inc.

Recommended reading

- Rain gardens & other bioretention systems, County Health rankings
- Meeting Hydrologic and Water Quality Goals through Targeted Bioretention Design. Journal of Environmental Engineering/Volume 138 Issue 6 - June 2012. William F. Hunt, M., Allen P. Davis, and Robert G. Traver
- Mitigation of Impervious Surface Hydrology Using Bioretention in North Carolina and Maryland. Journal of Hydrologic Engineering/Volume 14 Issue 4 - April 2009. Houng Li; Lucas J. Sharkey, William F. Hunt; and Allen P. Davis

References

- Adger, W. Neil. 2006. Vulnerability. Global Environmental Change 16:268–281.
- Barton, S. 2009. Human benefits of green spaces. University of Delaware Bulletin #137. 2009.
- Folke C. 2006. Resilience: the emergence of a perspective for social–ecological systems analyses. Global Environ Change. 16:253–267.
- Kazemi, F., S. Beecham, J. Gibbs, and R. Clay. 2009. Factors affecting terrestrial invertebrate diversity in bioretention basins in an Australian urban environment. Landscape and Urban Planning. Vol. 92:3-4:304-313.
- Kazemi, F., S. Beecham, and J. Gibbs. 2009. Streetscale bioretention basins in Melbourne and their effect on local biodiversity. Ecological Engineering. 35:1454-1465.
- Mehring, A.S., B. E. Hatt, D. Kraikittikun, B. D. Orelo, M. A. Rippy, S. B. Grant, J. P. Gonzalez, S. C. Jiang, R. F. Ambrose, and L. A. Levin. 2016. Soil invertebrates in Australian rain gardens and their potential roles in storage and processing of nitrogen. Ecological Engineering. 97:138-143.
- Moore, T., and W.F. Hunt. 2013. Predicting the carbon footprint of urban stormwater infrastructure. Ecological Engineering. Volume 58, September 2013, Pages 44-51.
- New York City Mayor's Office of Recovery and Resiliency. 2017. Preliminary Climate Resiliency Design Guidelines.

Soil amendments to enhance phosphorus sorption

Principal mechanisms for phosphorus (P) removal in bioretention are the filtration of particulate-bound P and chemical sorption of dissolved P (see Hunt et al., 2012). Most stormwater control measures (SCMs) capture particulate P by settling or filtration, but leave dissolved P (typically phosphates) untreated. This untreated P accounts on average for 45 percent of total phosphorus in stormwater runoff and can be up to 95 percent of the total phosphorus, depending on the storm event (Erickson et al., 2012). Dissolved phosphorus is bioavailable and represents a significant concern for surface water quality.

Phosphorus sorbing materials contain a metal cation (typically di or trivalent) that reacts with dissolved phosphorus to create an insoluble compound by adsorption or precipitation or both (Buda et al., 2012). Soil components and amendments that have been shown to be effective in increasing chemical sorption of dissolved P include

- iron filings (Erickson et al., 2012);
- steel wool (Erickson et al., 2007);

- native iron rich soils such as those in the Piedmont of the Mid and Southern Atlantic USA (Hunt et al 2012), or Krasnozem soil in Australia (Lucas and Greenway, 2011);
- Drinking Water Treatment Residuals (WTRs), which are a by-product of drinking water treatment and a source of aluminum and iron hydroxides (O'Neill and Davis, 2012a and 2012b, Hinman and Wulkan, 2012; Lucas and Greenway, 2011; Lucas and Greenway, 2010); and
- sorptive media (Imbrium) (Balch et al 2013)

Caution: Acceptable amendments include the following.

- 5 percent by volume elemental iron filings above IWS or elevated underdrain;
- minimum 5 percent by volume sorptive media above IWS or elevated underdrain;
- minimum 5 percent by weight water treatment residuals (WTR) to a depth of at least 10 centimeters; and
- other P sorptive amendments with supporting third party research results showing P reduction for at least 20 year lifespan, P credit commensurate with research results

Buda et al. (2012) provide a literature review of P-sorption amendments. Characteristics of ideal P-sorption amendments include low cost, high availability, low toxicity for soil and water resources, potential for reuse as a soil amendment once fully saturated, and no toxicity to plants, wildlife, or children. It is also crucial that soil amendments not negatively impact soil infiltration rate and the ability to grow vigorous plants. Some P sorptive amendments, such as water treatment residuals (WTRs), are waste products turned into a resource to reduce P in bioretention (or agricultural) soils. Results from much of the research to date on use of P-sorbing materials to reduce nutrients in stormwater effluent are promising, but much remains to be learned about lifespan and long term effects of P-sorbing materials on soils and plants.

Benefits

P sorptive amendments have been shown to provide effective P retention for the expected lifetime of bioretention facilities (e.g. Lucas and Greenway, 2011; O'Neill and Davis, 2012a and 2012b). The presence of healthy vegetation plays a crucial role in extending P reduction lifespan of amendments.

Types of P-sorbing materials

The primary P-sorbing chemicals are calcium (Ca), aluminum (Al) and iron (Fe). These are found in a variety of materials.

Limestone or calcareous sand

Combinations of C 33 sand with limestone or calcareous sand were tested in laboratory columns by Erickson et al. (2007). Limestone or calcareous sand showed strong retention of phosphorus but clogged the columns, resulting in hydraulic failure. On-going field studies are looking at the potential for calcium-based systems to remove phosphorus. Examples include studies by Ramsey-Washington Watershed District to determine effectiveness of spent lime and a permeable limestone barrier, and a study by Riley-Purgatory-Bluff Creek Watershed District to determine the effectiveness of a spent lime system. Long-term monitoring of these systems will provide useful information for determining if calcium-based systems can provide effective treatment for dissolved phosphorus.

Drinking Water Treatment Residuals (WTS)

Drinking-water treatment residuals are primarily sediment, metal (aluminum, iron or calcium) oxide/hydroxides, activated carbon, and lime removed from raw water during the water purification process (Agyin-Birikorang et al., 2009). WTRs are increasingly being used to control phosphorus in soils where phosphorus leaching may be problematic for water quality. Kawczyinski and Achtermann (1991) reported that landfilling is the predominant disposal method, followed by land application, sanitary sewer disposal, direct stream discharge, and lagooning. WTRs contain high concentrations of amorphous aluminum (Al) or iron (Fe), making them potential amendments for sorbing soil phosphorus.

Aluminum-based Water Treatment Residuals (WTRs)

O'Neill and Davis (2012a and 2012b) recommend a bioretention soil media of 5 percent WTR, 3 percent triple-shredded hardwood bark mulch, and 92 percent loamy sand for P reduction on the basis of batch, minicolumn, and large column studies. The life expectancy for this media was 20 years. In a comparison of bioretention soil medias (BSM's) with varying fines concentrations, they found that increasing the concentration of sand (i.e. decreasing fines) improved P reduction. They also found that hardwood bark mulch, a source of organic matter typically low in P, further improved P reduction (O'Neill and Davis 2012a). The authors contend that an oxalate-extractable aluminum-, iron-, and phosphorus-based metric, the oxalate ratio, can be used to predict P sorption capacity, and suggest that a media oxalate ratio of 20 to 40 is expected to meet P adsorption requirements for nutrient sensitive watersheds. This media adsorbed 88.5 percent of the applied P mass, compared to a non-WTR amended control media for which effluent P mass increased 71.2 increased.

O'Neill and Davis (2012b) state “This media consistently produced total phosphorus effluent mean event concentrations less than 25 micrograms per liter and exhibited a maximum effluent concentration of only 70 micrograms per liter”. Concentrations of P as low as 25 micrograms P per liter may be necessary to reduce eutrophication risk depending on receiving water conditions (U.S. Environmental Protection Agency (US EPA, 1986) in O’Neill and Davis, 2012a). References to additional studies are found in O’Neill and Davis (2012a and 2012b).

Iron-based Water Treatment Residuals (WTRs)

As reviewed in O’Neill and Davis (2012 a), one study of iron based WTRs found iron based WTRs to be ineffective to P reduction because they solubilized and released all adsorbed P in reducing conditions, but another more recent study found this may not be the case. According to Dr. Allen Davis (University of Maryland), iron based water treatment residuals “should work just as well, maybe better than Al. The concern with Fe is that if the media becomes anaerobic due to flooding or any other reason, the Fe can be reduced and will dissolve. It adds another layer of complexity to the system.” This concern can be addressed by designing the bioretention practice to ensure the layer where P sorbtion will occur stays aerobic.

Iron filings

Research by Erickson et al. (2012) suggests that the lifespan for iron enhanced sand filtration (5 percent iron) with a typical impervious area ratio should be at least 30 years. Dissolved phosphorus capture should be greater than 80 percent for more than 30 years (Erickson, 2010). Many agricultural studies have also found several forms of iron enhancements to be effective to capture P (e.g. Chardon et al., 2012; Stoner et al. 2012; literature review in Buda et al. 2012). Research showing that native iron-rich soils also have high P sorption capacity further supports giving dissolved P removal credit (e.g. Lucas and Greenway, 2011). Stenlund (2013 personal communication) has observed that adding iron to soil causes the soil to harden to a rock like medium, and recommends augering holes for plant growth into soils that have been amended with iron.

Imbrium Sorptive®MEDIA

Imbrium Sorptive®MEDIA, a proprietary P sorbing amendment available from Contech, is an engineered granular media containing aluminum oxide and iron oxide that demonstrates substantial capacity for adsorption of dissolved phosphorus from stormwater runoff. A recent study reported results from monitoring P reduction of 5 bioretention mesocosms with varying concentrations of Imbrium Sorptive®MEDIA (Balch et al 2013). The study is summarized below.

Five individual bioretention cells were monitored, each with 50 cm (20 inches) depth of soil that consisted of sand and 15 percent peat moss. The authors state “Four of [the cells] had different concentrations of Sorbtive® Media (3, 5, 10 and 17 percent by volume). The fifth cell contained only the sand/peat soil mix and no amendment, and therefore represented a control that provided the ability to determine how much phosphorus was retained by the sand/peat mix alone. The total volume of spiked artificial stormwater applied to each cell approximated the volume of cumulative runoff generated in this region [Canada] over a two-year period by a drainage area five times the size of a bioretention cell. At every phosphorus concentration, all the cells amended with Sorbtive® Media demonstrated much higher percent removal of phosphorus compared to the control cell with no Sorbtive® Media. The performance gap between the amended cells and the control cell widened as the phosphorus concentration increased. At the 0.2 percent target phosphorus concentration, mean dissolved phosphorus removal ranged 79 to 92 percent for the amended cells compared to 54 percent for the control cell. At the 0.8 percent target phosphorus concentration, mean dissolved phosphorus removal ranged 86 to 98 percent for the amended cells compared to 20 percent for the control cell. In the final week of the study, with 0.8 percent target phosphorus concentration in the artificial stormwater, percent removal of dissolved phosphorus was 82 percent for the 3 percent amendment, 97 to 98 percent for the 5, 10, and 17 percent amendments, and 11 percent for the control. These results demonstrate that the Sorbtive® Media maintained high phosphorus adsorptive capacity throughout the study, especially at the 5 percent and greater amendment levels.”

Researchers estimate that the lifespan for Imbrium should be at least 10 to 30 years, depending on P loading and performance goals (Garbon, 2013 personal communication; Contech Engineering, 2013). Contech Engineering (2013) estimated 45 percent dissolved P removal at 20 years after initial installation of 5 percent Sorptive media by volume.

Field studies with Imbrium are also underway in Wisconsin (Bannerman, 2013 personal communication). Additionally, Imbrium media has been used in an upflow filter on a North Carolina wet pond, resulting in greater than 80 percent removal of dissolved P during ten monitored storm events (Winston, 2013 personal communication).

To our knowledge, no field installations with Imbrium Sorptive®MEDIA have been monitored long term. Field studies to monitor long term performance of bioretention with P sorbing amendments are recommended to monitor clogging potential and P reduction performance over the bioretention lifespan.

Examples of other innovative applications

Using P-sorptive amendments to reduce effluent P content from BMP’s is a newly emerging field. Some applications of P-sorptive amendments that are promising but for which there is not sufficient research to recommend them as standard practices are discussed below.

Using by-products like gypsum, mining residuals, or drinking water treatment residuals in filters

Several researchers have developed ditch filters with P-sorbing materials to intercept surface and subsurface flow ditch water to trap dissolved P. The filters can be replaced as needed when the P-sorption sites are full (Schneider, 2013; Stoner et al., 2012). They report that "Overall, by-products that are elevated in oxalate Al or Fe, WS Ca [water soluble calcium], and BI [buffer index] serve as the best P sorbents in P removal structures, and screening for these properties allows comparison between materials for this potential use. The flow-through approach described in this paper for predicting design curves at specific [retention time] and inflow P combinations aids in predicting how much P can be removed and how long a specific material will last until P saturation if the P loading rate for a specific site is known." (Stoner et al., 2012)

Researching the use of such filters on effluent from bioretention systems is recommended, as this would likely be an effective technique for P reduction in bioretention systems on projects where use of filters and ability to replace them as needed is realistic and desirable. For research on by-products, testing of composition and leaching of potentially harmful chemicals (e.g. dissolved metals) should be undertaken to ensure public health.

Using drain pipes enveloped in Fe-coated sand

Groenenberg et al. (2013) tested the performance of a pipe drain enveloped with Fe-coated sand, a side product of the drinking water industry with a high ability to bind P from the (agricultural) drainage water. They report that "The results of this trial, encompassing more than one hydrological season, are very encouraging because the efficiency of this mitigation measure to remove P amounted to 94 percent. During the trial, the pipe drains were below the groundwater level for a prolonged time. Nevertheless, no reduction of Fe(III) in the Fe-coated sand occurred, which was most likely prevented by reduction of Mn oxides present in this material. The enveloped pipe drain was estimated to be able to lower the P concentration in the effluent to the desired water quality criterion for about 14 years. Manganese oxides are expected to be depleted after 5 to 10 years. The performance of the enveloped pipe drain, both in terms of its ability to remove P to a sufficiently low level and the stability of the Fe-coated sand under submerged conditions in the long term, needs prolonged experimental research." Application of this technique could also potentially be effective for reducing P in effluent from bioretention systems with underdrains. Unlike the filter application described in Schneider (2013), though, the iron around the pipe cannot easily be removed and replaced when the P binding sites are full. However, depending on P, Ca, and iron concentrations, there may be enough P sorption sites to last the lifespan of the bioretention system. This application is similar to bioretention systems currently being tested by Bannerman in Wisconsin (Bannerman, 2013 personal communication)

Rototilling Water Treatment Residuals into existing bioretention facilities

O'Neill and Davis (2012b) also suggest that established bioretention facilities could be retrofitted for increased P reduction by rototilling WTRs into the media, as agricultural surface application has been shown to be effective. Bioretention facilities may need

to be re-planted after roto-tilling WTRs into the media, however, as rototilling would likely damage roots of existing vegetation. Alternatively perhaps a different way could be found to incorporate WTRs into existing bioretention facilities, such as, perhaps by air spading out some of the existing soil around existing vegetation, and replacing the soil that was removed with bioretention soil media amended with WTR's. This technique could perhaps be used to renew P sorption capacity of bioretention facilities when P sorption sites are filled.

Applicability

- Removal of dissolved phosphorus requires a comparatively high hydraulic retention time, and therefore a deeper media (Hsieh et al., 2007 in Hunt et al 2012). Media depth should therefore be at least 0.6 meters, with 0.9 meters recommended (Hunt et al., 2012).
- Infiltration rates between 0.007 and 0.028 millimeters per second (1 to 4 inches per hour) work best, as this increases the hydraulic retention time, allowing for more sorption to occur (Hunt et al 2012).
- If the media is saturated where phosphorus is stored, P is likely to leach out. So if an internal water storage (IWS) layer is used, it should be located below the P-sequestering portion of the media. Therefore, a 0.45 to 0.6 meter (1.5 to 2 foot) separation is recommended between the top of the IWS layer and the media surface (Hunt et al 2012). The P-sorptive amendment should be located at least 0.5 feet above the top of the IWS zone (Winston, 2013).

Life cycle properties

P sorptive amendments have been shown to provide effective P retention for the expected lifetime of bioretention facilities (e.g. Lucas and Greenway, 2011; O'Neill and Davis, 2012a and 2012b).

Maintenance needs

Soil amendments to enhance P sorption typically do not increase bioretention maintenance needs. Water treatment residuals (WTR's) are fine textured, so systems with WTR's should be designed to minimize clogging. Hinman and Wulkan (2012) recommend adding shredded bark at 15 percent by volume for each 10 percent WTRs added by volume to compensate for the fine texture of WTRs.

Iron filings can be obtained with a size distribution similar to sand. Erickson et al (2012) found that hydraulic conductivity of a sand filter was not negatively affected when operated for a year with up to 10.7 percent iron filings, which is enough iron to capture a

significant percent of dissolved P.

Cost information

Soil amendments to enhance P sorption are a relatively low cost technique to improve long term dissolved P removal. Steel wool, for example, has been found to increase the material cost by 3 to 5 percent (Erickson et al., 2007). Iron filings cost less than steel wool per unit weight because they require less manufacturing to produce (Erickson et al., 2012). Since WTRs are byproducts of the water treatment process, they can often be procured for little or no cost.

References

- Agyin-Birikorang, Sampson, George A. O'Connor,Lee W. Jacobs, Konstantinos C. Makris, and Scott R. Brinto. 2007. *Long-Term Phosphorus Immobilization by a Drinking Water Treatment Residual*. J. ENVIRON. QUAL. 36:1:316-323.
- Beck, D.A., G.R. Johnson, and G.A. Spolek. 2011. *Amending green roof soil with biochar to affect runoff water quantity and quality*. Environmental Pollution 159(2011):2111-8.
- Buda, A.R., G. F. Koopmans, R. B. Bryant, and W. J. Chardon. 2012. *Emerging Technologies for Removing Nonpoint Phosphorus from Surface Water and Groundwater: Introduction*. J. Environ. Qual. 41:621–627.
- Chardon, W.J., J. E. Groenenberg, E. J. M. Temminghoff, and G. F. Koopmans. 2012. *Use of Reactive Materials to Bind Phosphorus*. J. Environ. Qual. 41:636–646.
- Contech Engineering. 2013. Sorbtive® Media AI 28x48 for Phosphorus Treatment. Application: Bioretention Soil Amendment 20-Year Service Life Performance Estimates.
- Erickson, A., J. Gulliver, and P. Weiss. 2007. Enhanced Sand Filtration for Storm Water Phosphorus Removal. J. Environ. Eng. 133(5), 485–497.
- Erickson, A. 2010. *Iron Enhanced Sand Filtration For Stormwater Phosphorus Removal*. Presentation given February 23rd, 2010.
- Erickson, A.J., J.S. Gulliver, and P.T. Weiss. 2012. *Capturing phosphates with iron enhanced sand filtration*. Water Research. 46(9): 3032–3042.
- Groenenberg JE, W.J. Chardon, G.F. Koopmans. 2013. *Reducing phosphorus loading of surface water using iron-coated sand*. Journal of Environmental Quality. 42(1):250-9.
- Hinman, C., and B. Wulkan. 2012. Low Impact Development. Technical Guidance Manual for Puget Sound. Publication No. PSP 2012-3.
- Hunt, W., Davis, A., and R. Traver. 2012. *Meeting Hydrologic and Water Quality Goals through Targeted Bioretention Design*. J. Environ. Eng. 138(6): 698–707.

- Kawczyinski, E., Achtermann, V. 1991. *A water industry database report on residuals handling*. In Proc. of the AWWA/WEF Joint Residuals Conf. Durham, NC. 11-14 Aug. American Water Works Association. Denver, Colorado. p. 6b-1 to 6b-5.
- Lucas, W. C. and M. Greenway. 2011. *Phosphorus Retention by Bioretention Mecocosms Using Media Formulated for Phosphorus Sorption: Response to Accelerated Loads*. Journal of Irrigation and Drainage Engineering. 137(3): 144-152.
- O'Neill, S. W., and A. P. Davis, A. P. 2012a. *Water treatment residual as a bioretention amendment for phosphorus. I. Evaluation studies*. J. Environ. Eng. 138(3): 318–327.
- O'Neill, S. W., and A. P. Davis. 2012b. *Water treatment residual as a bioretention amendment for phosphorus. II. long-term column studies*. J. Environ. Eng., 138(3), 328–336.
- Schneider, C. Re-using byproducts in agricultural fields. 2013.CSA News. Crop Science Society of America, Soil Society of America, American Society of Agronomy. April 2013 issue.
- Stoner, D., C. Penn, J. McGrath, and J. Warren. 2012. *Phosphorus Removal with By-Products in a Flow-Through Setting*. J. Environ. Qual. 41:654–663.

Summary of permit requirements

The following are requirements of the Construction Stormwater General Permit.

Infiltration systems (bioinfiltration)

- Permittees must design infiltration systems such that pre-existing hydrologic conditions of wetlands in the vicinity are not impacted (e.g., inundation or breaching a perched water table supporting a wetland).
- Permittees must not excavate infiltration systems to final grade, or within three (3) feet of final grade, until the contributing drainage area has been constructed and fully stabilized unless they provide rigorous erosion prevention and sediment controls (e.g., diversion berms) to keep sediment and runoff completely away from the infiltration area.
- When excavating an infiltration system to within three (3) feet of final grade, permittees must stake off and mark the area so heavy construction vehicles or equipment do not compact the soil in the infiltration area.
- Permittees must use a pretreatment device such as a vegetated filter strip, forebay, or water quality inlet (e.g., grit chamber) to remove solids, floating materials, and oil and grease from the runoff, to the maximum extent practicable, before the system routes stormwater to the infiltration system.
- Permittees must design infiltration systems to provide a water quality volume (calculated as an instantaneous volume) of one (1) inch of runoff, or one (1) inch minus the volume of stormwater treated by another system on the site, from the net increase of impervious surfaces created by the project.

- Permittees must design the infiltration system to discharge all stormwater (including stormwater in excess of the water quality volume) routed to the system through the uppermost soil surface or engineered media surface within 48 hours. Permittees must route additional flows that cannot infiltrate within 48 hours to bypass the system through a stabilized discharge point.
- Permittees must provide a means to visually verify the infiltration system is discharging through the soil surface or filter media surface within 48 hours or less.
- Permittees must provide at least one soil boring, test pit or infiltrometer test in the location of the infiltration practice for determining infiltration rates.
- For design purposes, permittees must divide field measured infiltration rates by 2 as a safety factor or permittees can use soil-boring results with the infiltration rate chart in the Minnesota Stormwater Manual to determine design infiltration rates. When soil borings indicate type A soils, permittees should perform field measurements to verify the rate is not above 8.3 inches per hour. This permit prohibits infiltration if the field measured infiltration rate is above 8.3 inches per hour.
- Permittees must employ appropriate on-site testing ensure a minimum of three (3) feet of separation from the seasonally saturated soils (or from bedrock) and the bottom of the proposed infiltration system.
- Permittees must design a maintenance access, typically eight (8) feet wide, for the infiltration system.
- This permit prohibits permittees from constructing infiltration systems that receive runoff from vehicle fueling and maintenance areas including construction of infiltration systems not required by this permit.
- This permit prohibits permittees from constructing infiltration systems where infiltrating stormwater may mobilize high levels of contaminants in soil or groundwater. Permittees must either complete the MPCA's contamination screening checklist or conduct their own assessment to determine the suitability for infiltration. Permittees must retain the checklist or assessment with the SWPPP.

For more information and to access the MPCA's "contamination screening checklist" see the Minnesota Stormwater Manual.

- This permit prohibits permittees from constructing infiltration systems in areas where soil infiltration rates (including amended soils) are field measured at more than 8.3 inches per hour unless they amend soils to slow the infiltration rate below 8.3 inches per hour.
- This permit prohibits permittees from constructing infiltration systems in areas with less than three (3) feet of separation distance from the bottom of the infiltration system to the elevation of the seasonally saturated soils or the top of bedrock.
- This permit prohibits permittees from constructing infiltration systems in areas of predominately Hydrologic Soil Group type D soils (clay).
- This permit prohibits permittees from constructing infiltration systems within a Drinking Water Supply Management Area (DWSMA) as defined in Minn. R. 4720.5100, subp. 13, if the system will be located:

  a. in an Emergency Response Area (ERA) within a DWSMA classified as having high or very high vulnerability as defined by the Minnesota Department of Health; or

b. in an ERA within a DWSMA classified as moderate vulnerability unless a regulated MS4 Permittee performed or approved a higher level of engineering review sufficient to provide a functioning treatment system and to prevent adverse impacts to groundwater; or
c. outside of an ERA within a DWSMA classified as having high or very high vulnerability, unless a regulated MS4 Permittee performed or approved a higher level of engineering review sufficient to provide a functioning treatment system and to prevent adverse impacts to groundwater.

See "higher level of engineering review" in the Minnesota Stormwater Manual for more information.

- This permit prohibits permittees from constructing infiltration systems in areas within 1,000 feet upgradient or 100 feet downgradient of active karst features.
- This permit prohibits permittees from constructing infiltration systems in areas that receive runoff from the following industrial facilities not authorized to infiltrate stormwater under the NPDES stormwater permit for industrial activities: automobile salvage yards; scrap recycling and waste recycling facilities; hazardous waste treatment, storage, or disposal facilities; or air transportation facilities that conduct deicing activities.

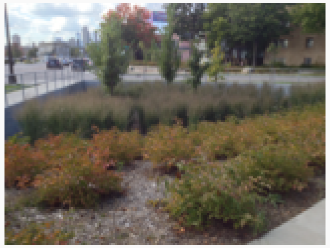
Filtration systems (biofiltration)

- Permittees must not install filter media until they construct and fully stabilize the contributing drainage area unless they provide rigorous erosion prevention and sediment controls (e.g., diversion berms) to keep sediment and runoff completely away from the filtration area.
- Permittees must design filtration systems to remove at least 80 percent of TSS.
- Permittees must use a pretreatment device such as a vegetated filter strip, small sedimentation basin, water quality inlet, forebay or hydrodynamic separator to remove settleable solids, floating materials, and oils and grease from the runoff, to the maximum extent practicable, before runoff enters the filtration system.
- Permittees must design filtration systems to treat a water quality volume (calculated as an instantaneous volume) of one (1) inch of runoff, or one (1) inch minus the volume of stormwater treated by another system on the site, from the net increase of impervious surfaces created by the project.
- Permittees must design the filtration system to discharge all stormwater (including stormwater in excess of the water quality volume) routed to the system through the uppermost soil surface or engineered media surface within 48 hours. Additional flows that the system cannot filter within 48 hours must bypass the system or discharge through an emergency overflow.
- Permittees must design the filtration system to provide a means to visually verify the system is discharging through the soil surface or filter media within 48 hours.
- Permittees must employ appropriate on-site testing to ensure a minimum of three (3) feet of separation between the seasonally saturated soils (or from bedrock) and the bottom of the proposed filtration system.

- Permittees must ensure that filtration systems with less than three (3) feet of separation between seasonally saturated soils or from bedrock are constructed with an impermeable liner.
- The permittees must design a maintenance access, typically eight (8) feet wide, for the filtration system.

Bioretention photo gallery

Click on an image for enlarged view.



Click on an image for enlarged view.

Photo courtesy of Katherine McLellan.

Image Courtesy of Emmons & Olivier Resources, Inc.

External resources

- Maryland Stormwater Design Manual. [9]
- New Jersey Best Management Practices Manual. [10]
- North Carolina Department of Environment and Natural Resources - Stormwater BMP Manual. [11]
- Price George's County Programs & Planning Division Department of Environmental Resources - Bioretention Manual. [12]
- Vermont Stormwater Manual - Volume I. [13]
- Virginia Department of Conservation and Recreation. Design specification 9 - Bioretention. [14]

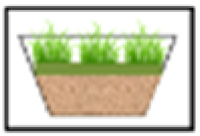
References for bioretention

- ASCE/EPA. International BMP Database.
- Atlanta Regional Commission. Georgia Stormwater Management Manual. 2001.
- Bannerman, Roger. 2013. Personal Communication.
- Bannerman, R. 2012. WDNR What Are We Learning About Selecting a Soil Media for Bioretention Systems? Presentation to NASECA February 2, 2012.
- Bouwer, H. and R. C. Rice. 1989. Effect of Water Depth in Ground-water Recharge Basins on Infiltration. Journal of Irrigation and Drainage Engineering, Vol. 115, No. 4, pp. 556-567.
- Claytor, R.A., and T.R. Schueler. 1996. *Design of Stormwater Filtering Systems*. The Center for Watershed Protection, Silver Spring, MD.
- Dakota County Soil and Water Conservation District. 10/25/2012. Dakota County Jenson Lake Stormwater Retrofit Project Factsheet.
- Dakota County Soil and Water Conservation District. 2011. Low Impact Development Standards For Dakota County, Minnesota.
- Davis, A.P., M. Shokouhian, H. Sharma and C. Minani. 1998. *Optimization of Bioretention for Design for Water Quality and Hydrologic Characteristics*. n.p.
- Glover, R., 1960. Mathematical Derivations as Pertain to Ground-water Recharge. Report CER60REG70. Agricultural Research Service, USDA, Fort Collins, Colorado. 81 pp.
- Hantush, M. 1967. Growth and Decay of Ground-water-Mounds in Response to Uniform Percolation. Water Resources Research. 3(1): 227-234.
- Hathaway, J. M., Hunt, W. F., Graves, A. K., and Wright, J. D. 2011. *Field evaluation of bioretention indicator bacteria sequestration in Wilmington NC*. J. Environ. Eng., 137(12), 1103–1113.
- Hunt, W.F. and W.G. Lord. 2006. Bioretention Performance, Design, and Construction and Maintenance. North Carolina Cooperative Extension Service.
- Hunt, W., Davis, A., and Traver, R. 2012. *Meeting Hydrologic and Water Quality Goals through Targeted Bioretention Design*. J. Environ. Eng., 138(6), 698–707. doi: 10.1061/(ASCE)`EE.1943-7870.0000504
- Isensee, Mike. 2013. Personal Communication.
- Low Impact Design Center, Inc. 2005. Urban Design Tools, Internet Resource. Beltsville, MD.
- Metropolitan Council. 2001. Minnesota Urban Small Sites BMP Manual, Stormwater Best Management Practice for Cold Climates. St. Paul, MN.
- Natural Resources Conservation Service. 1986. Urban Hydrology for Small Watersheds. Technical Release 55 (TR-55).
- Prince George's County. 2002. Bioretention Manual. Programs & Planning Division Department of Environmental Resources, Landover, MD.

- Rawls, W., D. Brakensiek, and K. Saxton, 1982. Estimation of Soil Water Properties. Transactions of the American Society of Agricultural Engineers. Vol. 25, No. 5, pp. 1316 – 1320 and 1328.
- Rawls, W., D. Giminez, and R. Grossman. 1998. Use of Soil Texture, Bulk Density and Slope of water Retention Curve to Predict Saturated Hydraulic Conductivity. ASAE. Vol. 41(4). pp. 983 – 988.
- Shaw, D. and R. Schmidt. 2003. Plants for Stormwater Design. Minnesota Pollution Control Agency, St. Paul, MN.
- South Washington Watershed District (SWWD). 2005. 2004 Infiltration Monitoring Program Final Report. Emmons and Olivier Resources, Inc.
- State of New Jersey]. 2004. New Jersey Stormwater Best Management Practices Manual. Department of Watershed Management. NJ.
- Tornes, L.H.. 2005. Effects of Rain Gardens on the Quality of Water in the Minneapolis-St. Paul Metropolitan Area of Minnesota. 2002-04. US Geological Survey, Scientific Investigations Report 2005-5189. 22p.
- Vermont Agency of Natural resources. 2002. Vermont Stormwater Management Manual.
- Winer, R. 2000. National Pollutant Removal Performance Database. Center for Watershed Protection.
- Wisconsin DNR. 2004. Bioretention for Infiltration Conservation Practice Standard 1004.

MIDS calculator

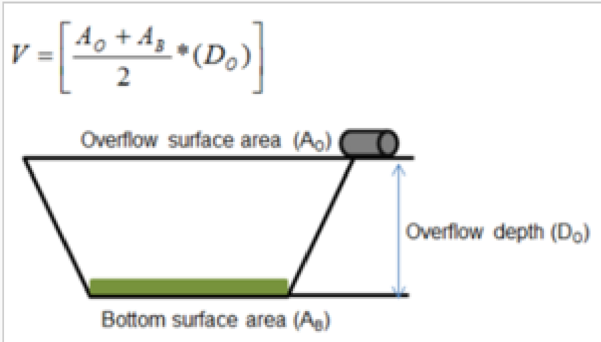
The MIDS calculator includes bioinfiltration (bioretention with no underdrain) and biofiltration (bioretention with an underdrain) as BMP options. For biofiltration the underdrain may be at or raised above the bottom of the BMP. Below is a summary of requirements, recommendations and other information for using the Minimal Impacts Design Standards (MIDS) calculator for bioretention BMPs. Links to MIDS pages and the MIDS calculator are included at the bottom of this page.



Symbol for bioinfiltration (Bioretention basin (w/o underdrain))

Bioinfiltration (Bioretention with no underdrain)

Information: Note the term Bioinfiltration corresponds with a bioretention system with no underdrain. See Bioretention terminology



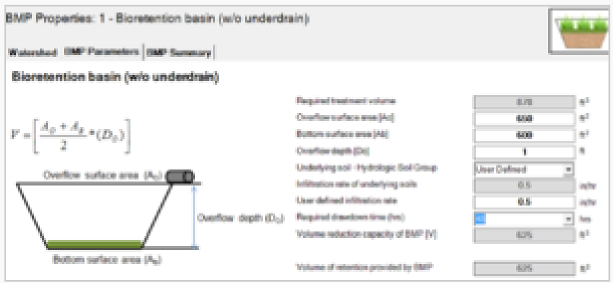
in MIDS calculator.

For a bioinfiltration system all water captured by the BMP is infiltrated between rain events into the underlying soil. All pollutants in the infiltrated water are captured. Water that bypasses the BMP is not treated.

Schematic showing the inputs needed for bioinfiltration in the MIDS calculator. The equation used to calculate volume captured by the BMP is included.

Methodology

The volume of runoff water delivered to the BMP equals the performance goal (1.1 inches or user specified performance goal) times the impervious area draining to the BMP. The BMP must be sized correctly in the calculator to capture the water delivered to the BMP. Water captured by the BMP is stored above the media and below the overflow point of the BMP. The runoff volume is considered to instantaneously enter the BMP. The captured volume is therefore equal to the basin depth times the average surface area of the basin ((overflow surface area + bottom surface area) divided by 2).



Screen shot from MIDS calculator showing user inputs needed for a bioretention system with no underdrain.

Water infiltrates at a rate equal to the saturated conductivity of the media below the ponded depth of the BMP. The most restrictive layer (lowest conductivity) within 5 feet of the bottom of the ponded water is used in the calculation. Captured water must drain within the specified drawdown time (48 or 24 hours).

MIDS calculator user inputs for bioinfiltration

For bioinfiltration systems, the user must input the overflow surface area (the area of the BMP at the point where overflow occurs), the bottom surface area (the area at the bottom of the basin, just above the media), the overflow depth (the depth between the overflow surface area and the bottom surface area), the underlying soil - Hydrologic Soil Group (Hydrologic Soil Group (HSG) A, B, C, or D) and the required drawdown time (48 hours or in the case of trout streams, 24 hours). These are discussed below.

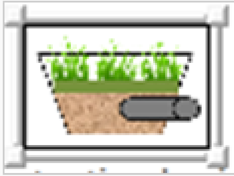
- **Overflow surface area (A_o)**: This is the area of the BMP at the lowest outlet point from the BMP. The user inputs this value in square feet.
- **Bottom surface area (A_b)**: This is the surface area at the bottom of the ponded water within the BMP. This is therefore the area at the surface of the media. The user inputs this value in square feet.
- **Overflow depth (D_o)**: This is maximum depth of ponded water within the BMP (distance from the overflow elevation to the top of the soil or media. The user inputs this this value in feet. The maximum value for this depth is 1.5 feet.

- **Underlying soil - Hydrologic Soil Group**: The user selects the most restrictive soil (lowest hydraulic conductivity) within three feet of the soil/media surface in the bioinfiltration basin. There are 14 soil options for the user. These correspond with soils and infiltration rates contained inthis Manual. The user may also enter a different value. The maximum allowable infiltration rate is 1.63 inches per hour.
- **Required drawdown time (hrs)**: This is the time the water captured by the BMP must drain into the underlying soil/media. The user may select 48 or 24 hours. The MPCA Construction Stormwater General Permit requires drawdown within 48 hours, but 24 hours is Highly Recommended when discharges are to a trout stream. The user will encounter an error if the water stored in the BMP cannot drawdown in the required time.

Assumptions

- The bioretention basin has been properly designed, constructed and will be properly maintained.
- Stormwater runoff entering the bioretention basin has undergone pretreatment
- The soil/media having the lowest hydraulic conductivity in the upper three feet of soil/media below the ponding area is input as the soil.
- Stormwater captured by the BMP enters the BMP instantaneously and is initially ponded within the BMP. Note this will underestimate actual infiltration since some water will enter the soil/media during a rain event, thus creating more volume for storage in the BMP.

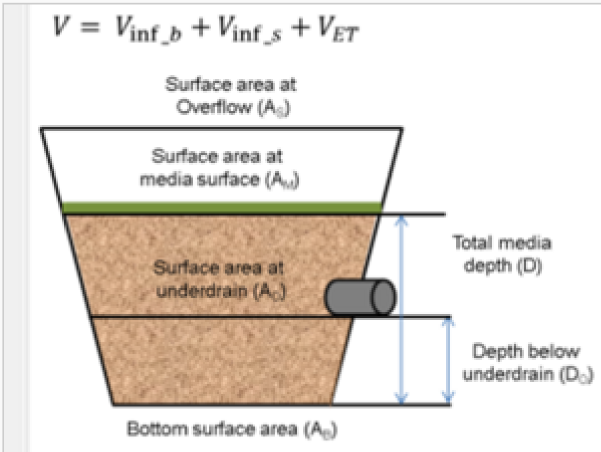
Biofiltration with underdrain at the bottom



Symbol for biofiltration (bioretention with underdrain) in MIDS calculator.

Information: Note the term Biofiltration corresponds with a bioretention system with an underdrain. The underdrain can be at or raised above the bottom of the system. See Bioretention terminology

For a biofiltration system with the underdrain at the bottom, most of the water captured by the BMP is lost to the underdrain. However some water infiltrates through

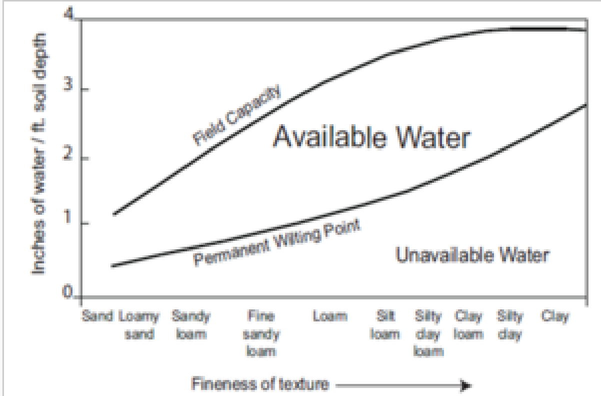


the basin bottom and sidewalls. Evapotranspiration also occurs from vegetation in the biofiltration BMP.

Schematic showing the inputs needed for biofiltration in the MIDS calculator. The equation used to calculate volume captured by the BMP is included.

Methodology

The volume of water delivered to the BMP equals the performance goal (1.1 inches or user specified performance goal) times the impervious area draining to the BMP. Unlike bioinfiltration, the volume of water captured by the BMP is a function of the media depth rather than the depth of water that can be ponded above the soil/media surface. The volume is considered to instantaneously enter the BMP. The captured volume is therefore equal to the total media depth times the ((surface area at media surface + bottom surface area)divided by 2).



Plot showing available water capacity over a range of soil textures. Available water is calculated as the difference, in inches of water per foot of soil depth, between field capacity and permananet wilting point, divided by 12 to convert to a fraction. Ohio Agronomy Guide, 14th edition, Bulletin 472-05

The depth of the basin does not affect the volume or mass of pollutant retained by the BMP. Most of the water entering the BMP will pass through the underdrain. Because this water passes through the biofiltration media, treatment is provided for TSS and particulate phosphorus but not for dissolved phosphorus. Some water is captured by the BMP as a result of infiltration through the bottom of the BMP, infiltration through the sidewalls of the BMP, and evapotranspiration from plants in the BMP.

The volume of water lost out the bottom equals 0.06 inches per hour times the surface area at at the underdrain times the drawdown time. The default was set at 0.06 inches per hour to represent a D soil. This value was set at this low rate because it is assumed most of the water will pass through the underdrain before it can infiltrate through the bottom of the BMP. This may be a conservative assumption if underdrains are small, spaced far apart, and the underlying soil has an infiltration rate greater than 0.06 inches per hour. Conversely, more closely spaced or larger underdrains may allow the basin to drain in less than the required drawdown time, which results in a slight overestimation of infiltration loss through the basin bottom.

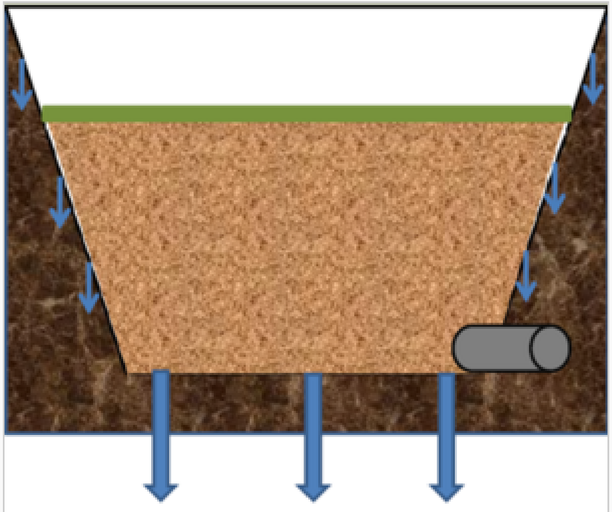
Water lost from a sloped sidewall is considered to infiltrate vertically into the surrounding soil. This volume equals the (surface area at overflow minus the bottom surface area) times 0.06 inches per hour times one-half of the drawdown time. The drawdown time is reduced by a factor of 2 to account for drop in water level within the BMP over the 48 hour period. The drop in water level is therefore considered to be linear over the drawdown time.

The volume of water lost through evapotranspiration (ET) is assumed to be the smaller of two calculated values.

- potential ET is equal to the amount of water stored in the biofiltration basin between field capacity and the wilting point.
- measured ET is the amount of water lost to ET as measured using available data. Pan evaporation (PE)measurements collected at the University of Minnesota Southwest Experiment Station at Lamberton were used to estimate an average daily PE. A rate of 0.2 inches per day was used, which is an intermediate value between the summertime maximum rate and the lowest rates in October. PE is converted to ET by multiplying PE by 0.5. ET is considered to occur over a 3 day period. therefore, the measured ET volume equals the media surface area times the daily ET rate times 3 days.

These two values are compared and the volume lost to ET is the smaller of the two values.

If the user specifies that a liner exists either at the sidewalls or bottom of the basin, no volume credit is given for these terms. The ET credit is provided regardless of the presence of a liner.



Schematic showing the process of water loss due to infiltration for a biofiltration system with an underdrain at the bottom. Water is lost through vertical infiltration out the basin bottom and sidewalls. Note that if sidewalls are vertical, there is no water loss through the sidewalls.

MIDS calculator user inputs for biofiltration with underdrain at bottom

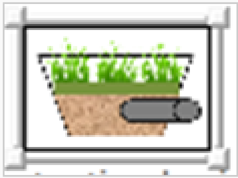
For biofiltration systems with an underdrain at the bottom, the user must indicate the underdrain is not elevated above native soils. The user must indicate whether either the bottom or sides of the basin are lined with an impermeable liner. The user must also input the overflow surface area (the area of the BMP at the point where overflow occurs; i.e. when the biofiltration basin is filled with water), the surface area at the media surface, the surface area of the bottom of the basin, the total media depth of the basin (the depth between the media surface and the bottom surface), the media field capacity minus wilting point, the media porosity, the underlying soil type (Hydrologic Soil Group (HSG) A, B, C, or D) and the time required for drawdown (48 hours or in the case of trout streams, 24 hours). These are discussed below.

- **Overflow surface area (A_o)**: This is the area of the BMP at the lowest outlet point from the BMP. The user inputs this value in square feet.
- **Surface area at media surface (A_m**: This is the area of the BMP at the media surface, in square feet.
- **Bottom surface area (A_b)**: This is the surface area at the bottom of the ponded water within the BMP. This is therefore the area at the surface of the media. The user inputs this value in square feet.
- **Media depth (D)**: This is the distance between the media surface and the bottom of the underdrain, in feet.
- **Media field capacity minus wilting point** - This is the amount of water stored in the media between field capacity and the permanent wilting point. This is water often considered to be available for uptake by plants. The figure at the right can be used to determine this value.
- **Media porosity** - This is the ratio of soil/media pore space to the total soil/media volume. Units are volume:volume (e.g. cubic centimeters per cubic centimeter). Typical values range from 0.25 to 0.40 for gravel, 0.25 to 0.50 for sand, 0.35 to 0.50 for silt, and 0.40 to 0.70 for clay.
- **Underlying soil - Hydrologic Soil Group**: The user selects the most restrictive soil (lowest hydraulic conductivity) within three feet of the soil/media surface in the bioinfiltration basin. There are 14 soil options for the user. These correspond with soils and infiltration rates contained inthis Manual. The user may also enter a different value. The maximum allowable infiltration rate is 1.63 inches per hour.
- **Required drawdown time (hrs)**: This is the time the water captured by the BMP must drain into the underlying soil/media. The user may select 48 or 24 hours. The MPCA Construction Stormwater General Permit requires drawdown within 48 hours, but 24 hours is Highly Recommended when discharges are to a trout stream. The user will encounter an error if the water stored in the BMP cannot drawdown in the required time.

Assumptions for biofiltration with underdrain at bottom

- The biofiltration basin has been properly designed, constructed and will be properly maintained.
- Stormwater runoff entering the biofiltration basin has undergone pretreatment
- Stormwater captured by the BMP enters the BMP media instantaneously. Note this will slightly underestimate actual infiltration since some water will infiltrate through the basin bottom and sidewalls during a rain event, thus creating more volume for storage in the BMP.
- Infiltration rates through the bottom and sidewalls of the basin are 0.06 inches per hour.
- Evapotranspiration is independent of plant type, plant density and weather conditions.

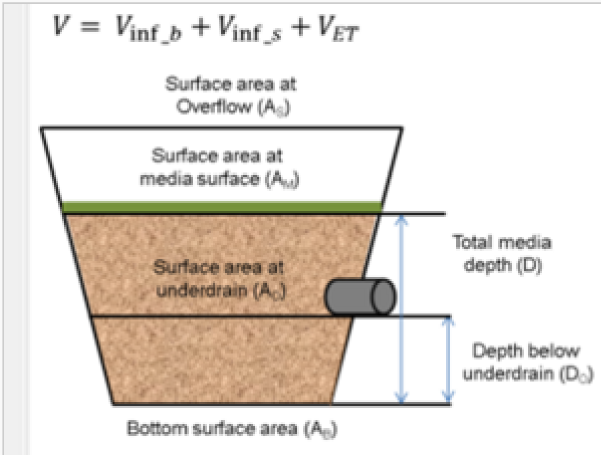
Biofiltration with a raised underdrain



Symbol for biofiltration (bioretention with underdrain) in MIDS calculator.

Information: Note the term Biofiltration corresponds with a bioretention system with an underdrain. The underdrain can be at or raised above the bottom of the system. See Bioretention terminology

For a biofiltration system with an underdrain elevated (raised) above the bottom of the basin, a volume credit is provided for the volume of water stored below the underdrain. this is in addition to volume credits given for infiltration through the bottom and sidewalls of the basin and for evapotranspiration (ET).



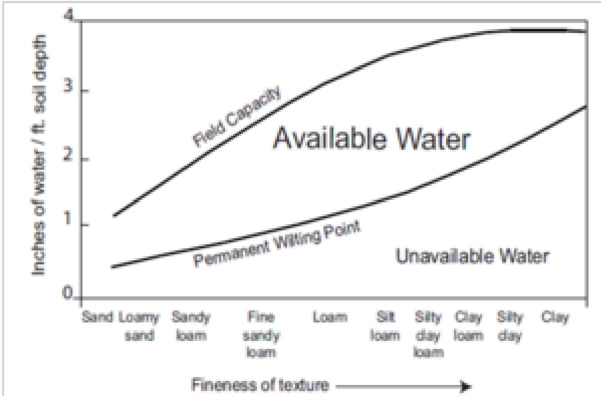
Schematic showing the inputs needed for biofiltration in the MIDS calculator. The equation used to calculate volume captured by the BMP is included.

Methodology

The methodology for a biofiltration system with an elevated underdrain is the same as for a biofiltration system with an underdrain at the bottom, with the exception that an additional credit is given for water stored below the underdrain.

The volume of water captured below the underdrain equals the ((surface area at the underdrain minus the surface area at the bottom of the basin) divided by two to give an average area), times the media depth below the underdrain. The stored water must drain within the specified drawdown time. The underlying soil controls the infiltration rate. The user must input the soil with the most restrictive hydraulic conductivity in the 5 feet directly below the basin.

A biofiltration system with an elevated underdrain thus behaves as a dual system, with the portion above the drain acting like a biofiltration system with an underdrain at the bottom and the portion below the underdrain acting like a bioinfiltration system.



Plot showing available water capacity over a range of soil textures. Available water is calculated as the difference, in inches of water per foot of soil depth, between field capacity and permananet wilting point, divided by 12 to convert to

a fraction. Ohio Agronomy Guide, 14th edition, Bulletin 472-05

MIDS calculator user inputs for biofiltration with an elevated underdrain

Inputs are the same as those for a biofiltration system with an underdrain at the bottom, with the exception that the user must specify the BMP has an elevated underdrain. This will prompt the user to provide inputs for the surface area at the bottom of the underdrain (square feet) and the media depth below the underdrain (feet).

Assumptions for biofiltration with an elevated underdrain

Assumptions are the same as for biofiltration with an underdrain at the borttom.

General discussion of other calculator features and assumptions

Bioinfiltration and biofiltration BMPs can be routed to other BMPs in the MIDS calculator (other than green roofs). All other BMPs in the calculator can be routed to bioinfiltration and biofiltration BMPs. The default storm event is 1.1 inches. This value can be changed by the user. The calculator will notify the user if the default is changed.

Total suspended solids (TSS), particulate phosphorus and dissolved phosphorus loads and reductions in loading are calculated using event mean concentrations (EMCs). Default EMCs are 54.5 milligrams per liter for TSS and 0.3 milligrams per liter for total phosphorus (particulate plus dissolved). These can be changed by the user. The calculator will notify the user if the default is changed.

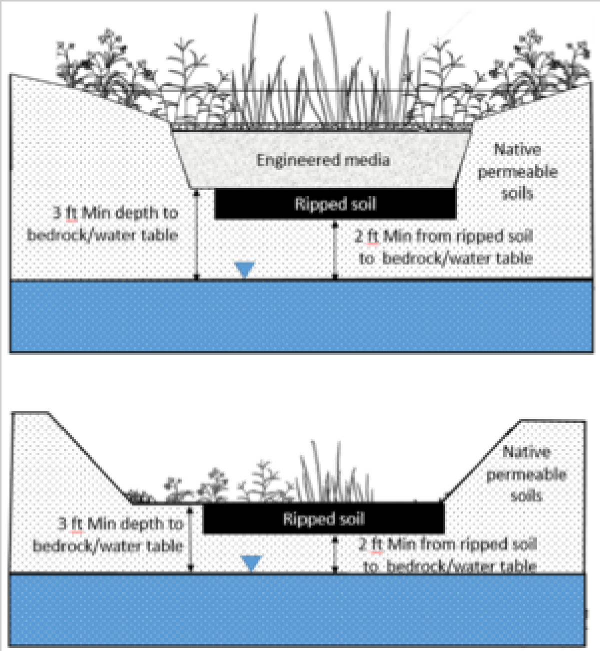
For bioinfiltration systems, all TSS and phosphorus captured by the BMP are reduced from the overall load delivered to the BMP. Note that more water may be delivered to the BMP than can be stored in the BMP. Excess water bypasses the BMP and receives no treatment from the BMP.

For biofiltration systems, phosphorus removal is 100 percent for all water that infiltrates through the bottom or sides of the basin. For water that is captured by an underdrain, phosphorus removal is 50 percent and TSS removal is 85 percent. It is assumed that 55 percent of all phosphorus is particulate and 45 percent is dissolved.

Requirements

Warning: The following are requirements of the Minnesota Construction Stormwater General Permit

- 3 foot separation from the bottom of the bioretention system to the seasonal high water table
- Use the most restrictive infiltration rate within 5 feet of the bottom of the BMP
- Drawdown time of 24 hours when the discharge is to trout streams
- For measured infiltration rates, apply a safety factor of 2
- Pretreatment



Measurement of depth from the bottom of the infiltration BMP to the seasonally high water table or bedrock. Note that there must be a minimum of 2 feet separation when soils beneath the BMP are ripped, with a total separation distance of 3 feet or more. Infiltration BMPs include any BMP that allows water to infiltrate into the underlying soil.

Recommendations

Caution: The following are recommendations for inputs into the MIDS calculator

- 5 acres or less for contributing area
- Maximum ponding depth of 18 inches, reduced to 6 inches if there is no site information
- Field tested infiltration rates rather than table values

Information

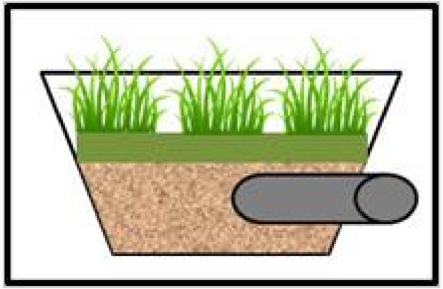
Information: The following information may be useful in determining inputs for the MIDS calculator

- Guidance on determining infiltration rates

- Information on site constraints (shallow soil, karst, etc.)
- Information on assessing BMPs
- Information on design metrics (high flow bypass, ponding depths, drawn down)
- Guidance on pretreatment
- Information on soil mixes
- Plant information, including species list that show water tolerance, potential effects of different species on infiltration rates, planting guidance
- Construction specifications
- Information on operation and maintenance of bioretention BMPs.

Links to MIDS pages

- Performance goals for new development, re-development and linear projects
- Flexible treatment options
- Ordinance goals
- MIDS calculator



Symbol for Bioretention basin (with underdrain) used in MIDS calculator.

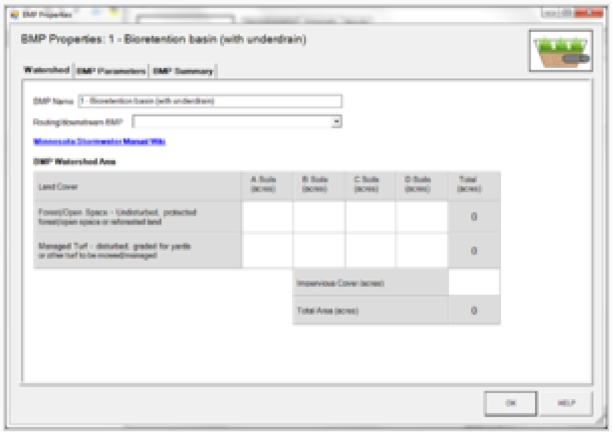
For a bioretention (aka biofiltration) BMP with an underdrain at the bottom of the engineered media, most of the stormwater captured by the BMP is filtered and lost to the underdrain. However, some stormwater infiltrates through the basin bottom and sidewalls if these do not have an impermeable liner. Volume retention also occurs by evapotranspiration through the vegetation in the biofiltration BMP. For biofiltration systems with an elevated underdrain, additional volume retention is achieved through infiltration of water stored in the pore spaces of the engineered media between the underdrain invert and the native soils. All pollutants in infiltrated water are credited as being removed, while a portion of the pollutant loads in the stormwater that flows through the underdrain are removed through filtration.

NOTE: A bioretention device with an installed underdrain is a type of biofiltration device, since some portion of the treated water is filtered and discharged downstream rather than infiltrated. MPCA believes that biofiltration is the more generally applicable term for this BMP type; but the reader will currently find both of these terms on relevant pages, due to MPCA's understanding that a variety of terms are currently common in stormwater management.

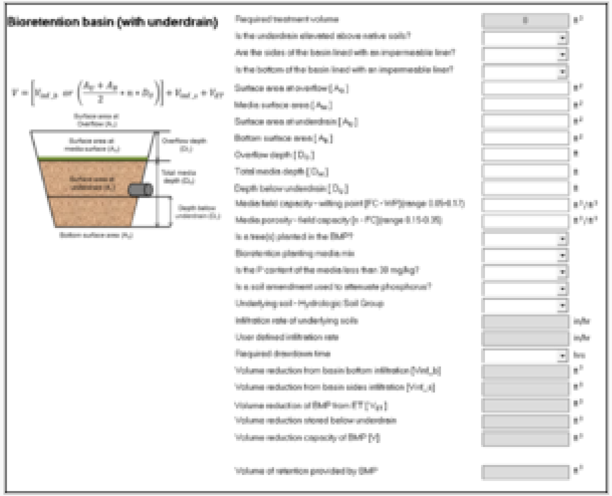
MIDS calculator user inputs for biofiltration basin (with underdrain)

For a biofiltration with underdrain system, the user must input the following parameters to calculate the volume and pollutant load reductions associated with the BMP.

- **Watershed tab:**
  - **BMP Name:** this cell is auto-filled but can be changed by the user.
  - **Routing/downstream BMP:** if this BMP is part of a treatment train and water is being routed from this BMP to another BMP, the user selects the name of the BMP to which water is being routed from the dropdown box. All water must be routed to a single downstream BMP. Note that the user must include the BMP receiving the routed water in the Schematic or the BMP will not appear in the dropdown box.
  - **BMP Watershed Area:** BMP watershed areas are the areas draining directly to the BMP. Values can be added for four soil types (Hydrologic Soil Groups (HSG) A, B, C, D) and for three Land Cover types (Forest/Open Space, Managed Turf, and Impervious). The surface area of the BMP should be included as a managed turf land cover of the hydrologic soil type of the native soils that are located under the BMP. Units are in acres.
- **BMP Parameters tab:**
  - **Is the underdrain elevated above native soils?:** This is a YES/NO question. Answering YES means the underdrain is elevated within the media (i.e., Biofiltration with a raised underdrain). This creates storage capacity between the underdrain and the native soils. Answering NO means that the underdrain is not elevated within the media and is directly above the native soils with no storage capacity below the underdrain (i.e., Biofiltration with underdrain at the bottom).
  - **Are the sides of the basin lined with an impermeable liner?:** This is a YES/NO question. Answering YES means the sides of the basin are lined, preventing water from infiltrating into the native soils. Answering NO means the sides are not lined and infiltration is allowed through the side of the basin into the native soils.



Screen shot Watershed tab for Bioretention basin (with underdrain).The user must input a value for impervious area or the BMP will not provide volume and pollutant reduction. Other fields are optional.



Screen shot of the BMP Parameters tab for a Bioretention basin (with

underdrain). The user must enter values for all blank cells.

- **Is the bottom of the basin lined with an impermeable liner?**: This is a YES/NO question. Answering YES means the bottom of the basin is lined, preventing water from infiltrating into the native soils. Answering NO means the bottom is not lined and infiltration is allowed through the bottom of the basin into the native soils.
- **Surface area at overflow (A_O):** This is the surface area of the BMP at the lowest outlet point of the surface overflow from the ponding area of the BMP. Units are in square feet.
- **Media surface area (A_M):** This is the surface area at the bottom of the ponded water within the BMP. This is therefore the area at the surface of the engineered media. Units are in square feet.
- **Surface area at underdrain (A_U):** This is the surface area of the BMP at the invert elevation of the underdrain. If the response to *"Is the underdrain elevated above native soils?"* is set to NO, then this cell will become inactive and populated with the *Bottom surface area* value. Units are in square feet.
- **Bottom surface area (A_B):** This is the surface area at the bottom of the engineered media. It represents the area where the engineered media changes to native soils. Units are in square feet
- **Overflow depth (D_O):** This is the maximum depth of ponded water within the BMP (i.e., vertical distance from the overflow elevation to the top of the soil or media). Units are in feet. The maximum allowable depth is 1.5 feet.
- **Total media depth (D_M):** This is the depth of the engineered media between the media surface and the native soils. Units are in feet.
- **Depth below underdrain (D_U):** This is the depth of the media between the underdrain invert and the native soils. If the response to *"Is the underdrain elevated above native soils?"* is set to NO, then this cell will become inactive and populated with a 0. Units are in feet.
- **Media field capacity minus wilting point (FC-WP):** This is the amount of water between field capacity and the permanent wilting point stored in the media above the underdrain. This is water often considered to be available for uptake by plants. If multiple types of media are used in the BMP, this value should be a weighted average of the soil water storage values of the media installed above the underdrain. Values for field capacity and wilting point based on soil type can be found here. Units are in cubic feet of water per cubic feet of media. The recommended range for this value is 0.05 to 0.17.
- **Media porosity minus field capacity (n - FC)** - This is the amount of water between media porosity and field capacity stored in the media between the underdrain invert and the bottom of the media (top of native soil). If multiple types of media are used in the BMP, this value should be a weighted average of the soil water storage values of the media installed between the underdrain and the native soils. Values for porosity and field capacity based on soil type can be found here. Units are in cubic feet of pore space per cubic feet of media. The recommended range for this value is 0.15 to 0.35.
- **Is a tree(s) planted in the BMP?:** This is a YES/NO question. If trees are planted within the biofiltration basin then additional volume loss associated with evapotranspiration will be applied.

- **Bioretention planting media mix:** The user selects the type of media mix installed for planting from a predefined list of media mixes: Media mix A (water quality blend), Media mix B (enhanced filtration blend), Media mix C (North Carolina State University water quality blend), Media mix D, or Other. This value is used to determine the annual phosphorus load reduction credit.
- **Is the P content of the media less than 30 mg/kg?:** This is a YES/NO question. The P content of the planting media should be tested using the Mehlich 3 test or an acceptable alternative method. Select YES if the P content of the planting media is less than 30 milligrams per kilogram and NO if it is greater. P content testing is not needed for planting media C or D; therefore, this item will automatically populate to YES if one of those two media types are selected. This value is used to determine the annual phosphorus load reduction credit.
- **Is a soil amendment used to attenuate phosphorus?:** This is a YES/NO question. Answer YES if the bioretention filter media contains soil amendments to enhance phosphorus sorption and NO if amendments are not used. This value is used to determine the annual phosphorus load reduction credit.
- **Underlying soil - Hydrologic Soil Group:** The user selects the most restrictive soil (lowest hydraulic conductivity) within the 5 feet below the media/native soil interface of the biofiltration basin. There are 14 soil options that fall into 4 different Hydrologic Soil Groups (Hydrologic Soil Group (HSG) A, B, C, or D) for the user. Once a soil type is selected, the corresponding infiltration rate will populate the *Infiltration rate of underlying soils* field. The user may also select *User Defined*. This selection will activate the *User Defined Infiltration Rate* cell, allowing the user to enter a different value from those in the predefined selection list. The maximum allowable infiltration rate is 1.63 inches per hour.
- **Required drawdown time:** This is the time in which the stormwater captured by and ponded within the BMP must drain into the underlying soil and/or flow through the underdrain. The user must select from predefined values of 48 or 24 hours. The MPCA Construction Stormwater General Permit requires drawdown within 48 hours, but 24 hours is *Highly Recommended* when discharges are to a trout stream. The calculator uses the underlying soil infiltration rate and the *Depth below underdrain* (D_U) to check if the BMP is meeting the drawdown time requirement. The user will encounter an error and be required to enter a new *Depth below underdrain* (D_U) if the stormwater stored in the BMP cannot drawdown in the required time. Note that the upper limit of 1.5 feet set for the *Overflow depth* (D_O) also serves to ensure that the required drawdown time is met.

- **BMP Summary tab:** The BMP Summary tab summarizes the volume and pollutant reductions provided by the specific BMP. It details the performance goal volume reductions and annual average volume, dissolved P, particulate P, and TSS load reductions. Included in the summary are the total volume and pollutant loads received by the BMP from its direct watershed, from upstream BMPs and a combined value of the two. Also included in the summary are the volume and pollutant load reductions provided by the BMP, along with the volume and pollutant loads that exit the BMP through the outflow. This outflow load and volume is what is routed to the downstream BMP, if one is defined in the *Watershed* tab. Finally, percent reductions are provided for the percent of the performance goal achieved, percent annual runoff volume retained, total percent annual particulate

phosphorus reduction, total percent annual dissolved phosphorus reduction, total percent annual TP reduction, and total percent annual TSS reduction.

Model input requirements and recommendations

If the following requirements for inputs into the MIDS calculator are not met, then an error message will inform the user to change the input to meet the requirement.

- *Overflow depth (D_O)* cannot be greater than 1.5 feet
- Surface areas must be equal to or less than all surface areas at higher elevations
- The *Depth below underdrain (D_U)* cannot be greater than the *Total media depth (D_M)*
- *Infiltration rate of underlying soils* cannot exceed 1.63 inches per hour
- If the user enters a value for *field capacity minus wilting point (FC-WP)* or *porosity minus field capacity (n-FC)* outside the recommended range a warning will appear. The user will not be required to enter a new value.
- The water below the underdrain must meet the user-specifed drawdown time requirement. The drawdown time requirement is checked by comparing the specified drawdown time with the calculated drawdown time (DDT_{calc}), given by

$DDT_{calc}=D_U / (I_R / 12)$

Where

D_U is the depth below the underdrain (ft); and
I_R is the infiltration rate of the native soils (in/hr).

If DDT_{calc} is greater than the user-specified required drawdown time then the user will be prompted to enter a new depth below the underdrain or infiltration rate of the native soils.

Methodology

Required treatment volume

Required treatment volume, or the volume of stormwater runoff delivered to the BMP, equals the performance goal (1.1 inches for MIDS or user-specified performance goal) times the impervious area draining to the BMP plus any water routed to the BMP from an

upstream BMP. This stormwater is delivered to the BMP instantaneously.

Volume reduction

The total estimated *Volume reduction capacity of BMP [V]* is the sum of infiltration and ET occurring in the biofiltration BMP, and is calculated with user-provided inputs. For this BMP, the location of the underdrain determines how the infiltration component is calculated. If the underdrain is located at the bottom of the BMP, then the infiltration credit is based on infiltration into the bottom of the BMP (V_{inf_b}) and into side slopes of the BMP above the underdrain (V_{inf_s}). In contrast, if the underdrain is elevated above the bottom of the BMP, then the infiltration credit is based on the volume capacity of the bioretention base (V_{BB}) between the underdrain and the native soils, and infiltration into the side slopes of the BMP above the underdrain (V_{inf_s}). Both types of underdrain configurations can receive credit for ET in the media above the underdrain (V_{ET}). A biofiltration system with an elevated underdrain thus behaves as a dual system, with the portion above the drain acting like a biofiltration system with an underdrain at the bottom and the portion below the underdrain acting like a bioinfiltration system.

The *Volume of retention provided by BMP* is the total instantaneous volume credit that can be claimed for that BMP, and is determined by comparing the *Volume reduction capacity of BMP [V]* to the *Required treatment volume*.

Volume reduction from infiltration

Underdrain located at bottom of engineered media: *Volume reduction from basin bottom infiltration (V_{inf_b})*

Even with an underdrain installed at the bottom of the engineered media, under saturated conditions some water will infiltrate through the bottom soils rather than pass through the underdrain. This *Volume reduction from basin bottom infiltration (V_{inf_b})* is given by

$V_{Inf_b} = I_R * (DDT) * A_B / (12in/ft) = 0.06 * (DDT) * A_B / (12in/ft)$

Where

> I_R is an infiltration rate into the native soils of 0.06 inches per hour;
> A_B is the surface area at the bottom of the BMP (ft^2); and
> DDT is the drawdown time (hr).

The default infiltration rate is set at 0.06 inches per hour to represent a D soil. This rate was selected because it is assumed most of the stormwater will pass through the underdrain before it can infiltrate through the bottom of the BMP. This may be a conservative

assumption if underdrains are small, spaced far apart, and the underlying soil has an infiltration rate greater than 0.06 inches per hour. Conversely, more closely spaced or larger underdrains may allow the basin to drain in less than the required drawdown time, resulting in a slight overestimation of (V_{inf_b}). If the user specifies that an impermeable liner is present at the bottom of the BMP, then no credit is given for infiltration into the bottom soils.

Elevated underdrain: *Volume reduction stored below the underdrain*

If the underdrain is elevated above the bottom of the BMP, then storage capacity becomes available in the media between the underdrain and the native soils. In systems with an elevated underdrain, this *Volume reduction stored below underdrain* is credited instead basin bottom infiltration (V_{Inf_b}) credit that is given when the underdrain is at the bottom of the engineered media. This *Volume reduction stored below underdrain* (V_U) is given by

$V_U= (A_U + A_B) / 2 * (n - FC) * D_U$

Where:

A_U is the surface area at the underdrain (ft^2);
A_B is the surface area at the bottom of the basin (ft^2);
(n - FC) is the media porosity minus field capacity of the soils; and
D_U is the depth of the media below the underdrain (ft).

The stored water must drain within the specified drawdown time. The underlying soil controls the infiltration rate. The user must input the soil with the most restrictive hydraulic conductivity in the 5 feet directly below the basin (i.e. below the bottom of the engineered media). If the user specifies that an impermeable liner is present at the bottom of the BMP, then no volume reduction credit is given for storage below the underdrain.

Volume reduction from basin sides infiltration (V_{inf_s}): underdrain elevated or at bottom of engineered media

Under saturated conditions within the filter media, water will infiltrate through any existing sloped sidewalls of the basin as the stormwater draws down through the underdrain. Stormwater lost from a sloped sidewall (V_{inf_s}) is considered to infiltrate vertically into the surrounding soil. This credit is calculated whether the underdrain is elevated or at the base of the engineered media. The volume of water infiltrated through the sidewalls is given by

$V_{Inf_s} = I_R * (DDT / 2) * (A_O - A_U) / (12in/ft) = 0.06 * (DDT / 2) * (A_O - A_U) / (12in/ft)$

Where:

A_O is the surface area at overflow (ft^2);
A_U is the surface area at the underdrain (ft^2); and
DDT is the drawdown time (hr).

Due to the fact that drawdown occurs as a continuous process, basin sides infiltration is not presumed to occur along the entire height of the sidewall during the entire drawdown time. For example, at "time zero", the entire sidewall should be exposed to saturated conditions and exhibit sidewall infiltration; but at the end of the drawdown period, there would theoretically be no section of the sidewall that is exposed to saturated conditions. Therefore, the drawdown time used in the calculation of (V_{inf_s}) is reduced by a factor of 2 to account for the drop in water level and to approximate the "average" water level within the BMP during the drawdown period. The drop in water level is thus assumed to be linear over the drawdown time. A conservative default infiltration rate of 0.06 inches per hour is used because it is assumed that most of the stormwater will pass through the underdrain before it can infiltrate through the sidewalls of the BMP. If the user specifies that an impermeable liner is present on the sides of the BMP or if the sidewalls are not sloped (i.e., $A_O = A_U$), then no credit is given for infiltration into the side soils.

Volume reduction from evapotranspiration (ET)

In addition to the credit given for infiltration, a biofiltration BMP can achieve volume reduction through ET. The volume of water lost through evapotranspiration (V_{ET}) is the smaller of two calculated values, potential ET and measured ET.

Potential ET (ET_{pot})

Potential ET (ET_{pot}) is equal to the amount of water stored between field capacity and the wilting point in the media above the underdrain, and is given by

$ET_{pot} = (D_M - D_U) * (A_M + A_U) / 2 * (FC - WP)$

Where

D_M is the total media depth (ft);
D_U is the depth under the underdrain (ft);
A_M is the surface area of the media (ft^2);
AU is the surface area at the underdrain (ft^2); and
(FC – WP) is the difference between field capacity and wilting point.

Measured ET (ET_{mea})

Measured ET (ET_{mea}) is the amount of water lost to ET as measured using available data. An average daily pan evaporation rate was estimated using previous measurements collected at the University of Minnesota Southwest Experiment Station at Lamberton, Minnesota (Source: Climate of Minnesota Part XII- The Hydrologic Cycle and Soil Water, 1979). A rate of 0.2 inches per day was selected, as this is an intermediate value between the summertime maximum rate and the lowest rates in October. Analysis of rainfall data indicates that a typical time period between precipitation events is 72 hours (3 days) in Minnesota. Therefore, a 3 day period is used to calculate the ET_{mea}. A factor of 0.5 is also applied to convert the pan evaporation rate to ET_{mea}. The ET_{mea} volume thus equals the media surface area (A_M) in square feet times the average daily ET rate in inches per day times 3 days.

$ET_{mea} = A_M * 0.2 in/day * 0.5 * 3 days / 12 in/ft = 0.025 A_M$

If trees are planted in the bioretention basin then ET_{mea} is multiplied by a factor of 3.

Comparison of volume reduction capacity with volume performance goal

The sum of the volumes lost to infiltration and to ET as calculated using the appropriate methods above gives the *Volume reduction capacity of BMP [V]*. The MIDS calculator compares the *Volume reduction capacity of BMP [V]* with the *Required treatment volume*, and the lesser of the two values is used to populate the *Volume of retention provided by BMP*. This comparison between potential and actual treatment volumes ensures that the BMP does not claim more credit than is due based on the actual amount of water routed to it. The *Volume of retention provided by BMP* is the actual volume credit the BMP receives toward the instantaneous performance goal. For example, if the BMP is oversized the user will only receive volume credit for the *Required treatment volume* routed to the BMP.

Annual volume retention is assessed by converting the instantaneous *Volume reduction capacity of BMP [V]* to an annual volume reduction percentage. This is accomplished through the use of performance curves developed from a range of modeling scenarios. These performance curves use the *Volume reduction capacity of BMP [V]*, the infiltration rate of the underlying soils, the percent imperviousness of the contributing watershed area, and the size of the contributing watershed to calculate the *Percent annual runoff volume retained* and annual *Retention volume provided by BMP*.

Recommended values for porosity, field capacity and wilting point for different soils.[1]

Link to this table.

Soil	Hydrologic soil group	Porosity [2] (volume/volume)	Field capacity (volume/volume)	Wilting point (volume/volume)	Porosity minus field capacity (volume/volume)[3]	Field capacity minus wilting point (volume/volume)[4]

Sand	A (GM, SW, or SP)	0.43	0.17	0.025 to 0.09	0.26	0.11
Loamy sand	A (GM, SW, or SP)	0.44	0.09	0.04	0.35	0.05
Sandy loam	A (GM, SW, or SP)	0.45	0.14	0.05	0.31	0.09
Loam	B (ML or OL)	0.47	0.25 to 0.32	0.09 to 0.15	0.19	0.16
Silt loam	B (ML or OL)	0.50	0.28	0.11	0.22	0.17
Sandy clay loam	C	0.4		0.07		
Clay loam	D	0.46	0.32	0.15	0.14	0.17
Silty clay loam	D	0.47 to 0.51	0.30 to 0.37	0.17 to 0.22	0.16	0.14
Sandy clay	D	0.43		0.11		
Silty clay	D	0.47		0.05		
Clay	D	0.47	0.32	0.20	0.15	0.12

[1]Sources of information include Saxton and Rawls (2006), Cornell University, USDA-NIFA, Minnesota Stormwater Manual

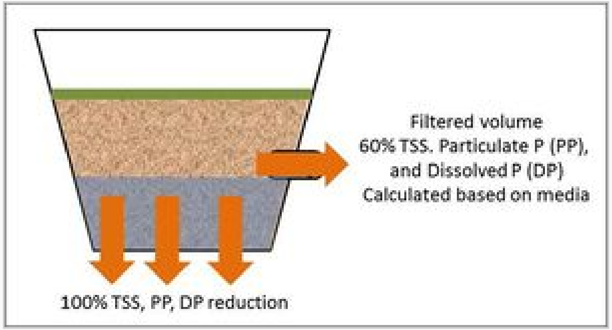
[2]Soil saturation is assumed to be equal to the porosity.

[3]This value may be used to represent the volume of water that will drain from a bioretention media.

[4]This value may be used to estimate the amount of water available for evapotranspiration

Pollutant reduction

Pollutant removal can be accomplished both via volume reducing and non-volume reducing processes in a biofiltration BMP. Pollutant load reductions are calculated on an annual basis and are thus dependent upon the volume of water retained by the BMP through infiltration and ET and the volume of water treated by filtration in the BMP.



Schematic showing how pollutant load reductions are calculated for Bioretention basin (with an underdrain). All TSS and phosphorus in infiltrated water is considered reduced. TSS loads are reduced by 60 percent for the portion of water filtered and captured by the underdrain. Phosphorus reductions in the filtered water are a function of the media and media thickness.

Pollutant reduction via volume reduction

The first step in calculating annual pollutant load reductions is to determine the annual *Retention volume provided by BMP* as discussed in the Volume reduction section. All pollutants in this retained water are considered captured for a 100 percent removal. Thus, while oversizing a BMP above the *Required treatment volume* will not provide additional credit towards the instantaneous volume performance goal, it may provide additional annual pollutant reduction through treatment of water beyond the *Required treatment volume*.

Pollutant reduction via non-volume reduction treatment

Stormwater that is routed to the BMP but not infiltrated or lost through ET is assumed to flow through the filter media and out the underdrain, and is indicated by the *Annual outflow volume* in the BMP Summary tab. The removal rate for TSS in this filtered stormwater is set at 60 percent.

Information: The Minnesota Stormwater Manual provides a TSS credit of 80 percent for biofiltration practices. A literature review suggests 80 percent may be high, but the Construction Stormwater (CSW) General Permit requires 80 percent reduction of TSS for filtration practices. Therefore, the CSW permit target cannot be achieved using the MIDS calculator. We created a MIDS calculator Excel file that utilizes 80 percent removal for biofiltration practices. Access the file at File:Corrected July 14.xls.

The removal rates for particulate phosphorus and dissolved phosphorus in the filtered stormwater depend on the user's input to three drop-down boxes: “Planting media mix”; “Is the P content of the media less than 30 mg/kg?”; and “Is a soil amendment used to attenuate phosphorus?”.

Particulate Phosphorus

The particulate phosphorus credit given for non-volume reduction treatment is either 0 percent or 80 percent depending on the media mix used and its P content.

- If Media Mix C or D is used, or if a media mix other than C or D is used and the soil phosphorus as measured using the Mehlich 3 test or a suitable alternative test is 30 milligrams per kilogram or less, then the annual particulate phosphorus reduction credit is 80 percent of the filtered water volume.
- If a media mix other than C or D is used and the soil phosphorus has not been determined or is greater than 30 milligrams per kilogram as measured using the Mehlich 3 test or a suitable alternative test, then the annual particulate phosphorus reduction credit is 0 percent of the filtered water volume.

NOTE: If the Olsen test is used to determine P content of the media mix, a simple conversion is required.

Dissolved Phosphorus

The dissolved phosphorus credit given for non-volume reduction treatment is between 0 percent and 60 percent depending on the media mix, the media P content, and if the media was amended to attenuate phosphorus.

- If Media Mix C or D is used, or if a media mix other than C or D is used and soil phosphorus as measured by the Mehlich 3 test or a suitable alternative test is 30 milligrams per kilogram or less, then the annual dissolved phosphorus credit applied to the filtered water volume, expressed as a percent, is given by

$credit = 20 percent (D_M- D_U) / 2 ft$

Where

D_M - D_U represents the media depth above the underdrain (ft).

The credit is calculated as a percent reduction with a maximum value of 20 percent for media depths above the underdrain greater than 2 feet. If the media depth above the underdrain is less than 2 feet the credit is reduced equivalently.

- If a media mix other than C or D is used and the soil phosphorus has not been determined or is greater than 30 milligrams per kilogram as measured using the Mehlich 3 test or a suitable alternative test, then the annual dissolved phosphorus credit is 0 percent of the filtered water volume.
- An additional annual dissolved phosphorus credit of 40 percent of the filtered water volume may be received if phosphorus-sorbing amendments are used. Acceptable amendments include the following:
  - 5 percent by volume elemental iron filings above the internal water storage (IWS) layer or elevated underdrain;
  - minimum 5 percent by volume sorptive media above IWS layer or elevated underdrain;
  - minimum 5 percent by weight water treatment residuals (WTR) to a depth of at least 3.9 inches (10 centimeters);
- For other proposed phosphorus-sorbing amendments: an additional annual dissolved phosphorus credit can be applied if and only if there is supporting third party research showing that this dissolved phosphorus reduction will occur for at least a 20-year lifespan. The credit may be commensurate with existing research results, with the understanding that the user may be asked to provide this documentation.

Phosphorus credits for bioretention systems with an underdrain.

Link to this table

Particulate phosphorus	Dissolved phosphorus
Is Media Mix C or D being used or, if using a mix other than C or D, is the media phosphorus content 30 mg/kg or less per the Mehlich 3 (or equivalent) test[1]? • If yes, particulate credit = 80% of the particulate fraction (assumed to be 55% of total P) • If no or unknown, particulate credit = 0% **TP removal credit** • Particulate fraction (55% of TP) * removal rate for that fraction (80%) = 0.55 * 0.80 = 0.44 or 44%	1. Is Media Mix C or D being used or, if using a mix other than C or D, is the media phosphorus content 30 mg/kg or less per the Mehlich 3 (or equivalent) test[1]? • If yes, credit as a % (up to a maximum of 20%) = 20 * (depth of media above underdrain, in feet/2) • If no or unknown, credit = 0% 2. Does the system include approved P-sorbing soil amendments[2]? • If yes, additional 40% credit **TP removal credit** • TP removal if dissolved credit is 20% = Dissolved fraction (45%) * removal rate for that fraction (20%) = 0.09 or 9

	percent • Adjust TP removal if depth is less than 2 feet • Adjust TP removal if dissolved credit is higher due to use of P-sorbing soil amendments

[1]Other widely accepted soil P tests may be used. Note: a basic conversion of test results may be necessary

[2]Acceptable P sorption amendments include

- 5% by volume elemental iron filings above IWS or elevated underdrain
- minimum 5% by volume sorptive media above IWS or elevated underdrain
- minimum 5% by weight water treatment residuals (WTR) to a depth of at least 10 cm
- other P sorptive amendments with supporting third party research results showing P reduction for at least 20 year lifespan, P credit commensurate with research results

NOTE: The user can modify event mean concentrations (EMCs) on the *Site Information* tab in the calculator. Default concentrations are 54.5 milligrams per liter for total suspended solids (TSS) and 0.3 milligrams per liter for total phosphorus (particulate plus dissolved). The calculator will notify the user if the default is changed. Changing the default EMC will result in changes to the total pounds of pollutant reduced.

Routing

A biofiltration basin can be routed to any other BMP, except for a green roof, a swale side slope, or any BMP that would cause stormwater to be rerouted back to the biofiltration basin already in the sequence. All BMPs can be routed to a biofiltration, except for a swale side slope BMP.

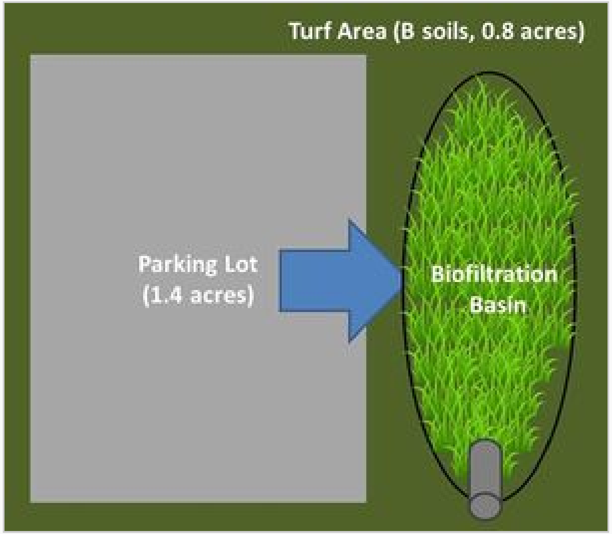
Assumptions for biofiltration basin with underdrain

The following general assumptions apply in calculating the credit for a biofiltration basin. If these assumptions are not followed the volume and pollutant reduction credits cannot be applied.

- The biofiltration basin has been properly designed, constructed, and will be properly maintained.
- Stormwater runoff entering the biofiltration basin has undergone pretreatment.

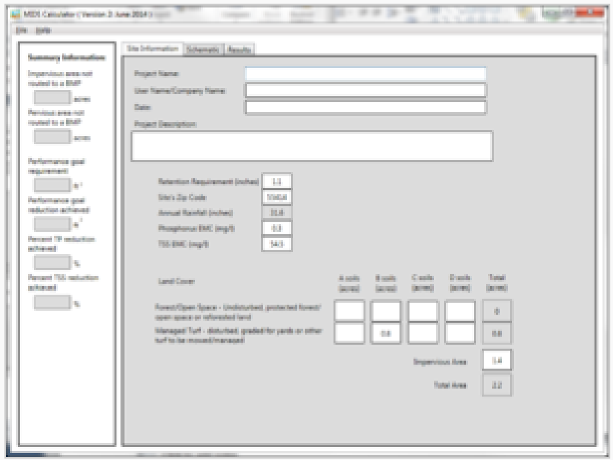
- Stormwater captured by the BMP enters the BMP media instantaneously. This will slightly underestimate actual infiltration since some water will infiltrate through the basin bottom and sidewalls during a rain event, thus creating more volume for storage in the BMP.
- Infiltration rates used to calculate the infiltration credit through the bottom and sidewalls of the basin are 0.06 inches per hour.
- Evapotranspiration is independent of plant type, plant density and weather conditions.

Biofiltration Basin with an elevated underdrain example (Version 2)



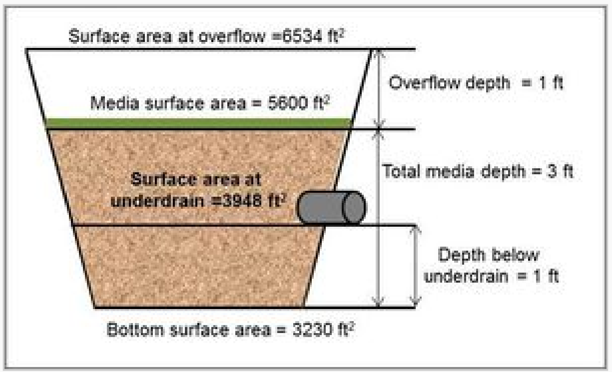
Schematic for the MIDS calculator example for bioretention with an underdrain. Impervious surface area is 1.4 acres. Pervious surface area, which includes a turf area and the bioretention basin, is 0.8 acres. See Step 1.

An unlined biofiltration basin with an elevated underdrain is to be constructed in a watershed that contains a 1.4 acre parking lot surrounded by 0.8 acres of pervious area (turf area and the bioretention BMP area). All of the runoff from the watershed will be treated by the biofiltration basin. The soils across the area have a unified soils classification of SM (HSG type B soil). The surface overflow is located 1 ft above the media surface.


Screen shot of Site Information tab for bioretention with elevated underdrain example. The user must input impervious acres and ZIP code. Other fields are optional. See Step 2.

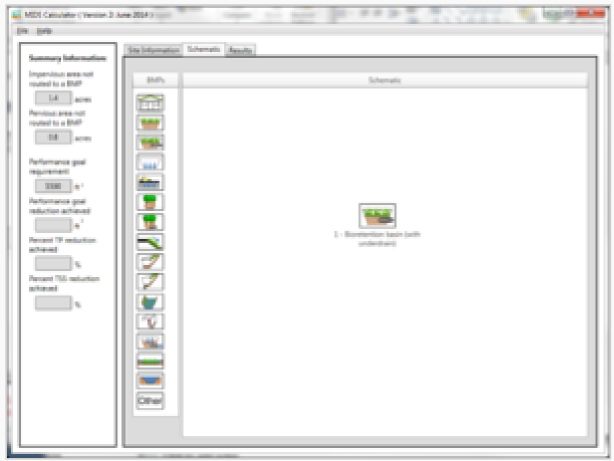
The surface area of the biofiltration basin at the overflow point will be 6534 square feet. The area is 5600 square feet at the media surface. The surface area at the invert of the underdrain will be 3948 square feet. The area at the media-soil interface is 3320 square feet. The total media depth will be 3 feet with 1 foot of media between the underdrain and the native soils. Following the MPCA Construction Stormwater General Permit requirement, the water below the underdrain in the biofiltration basin needs to drawdown in a 48 hour time period. The media will be Media Mix C, which is mostly sand resulting in a difference between the media wilting point and field capacity of 0.11 cubic feet per cubic foot and a difference between the media porosity and

field capacity of 0.26 cubic feet per cubic foot. The P content of the media is less than 30 mg/kg (milligrams per kilogram) and no soil amendments will be used to attenuate phosphorus. The following steps detail how this system would be set up in the MIDS calculator.



Schematic used for MIDS calculator example for bioretention with elevated underdrain. See Step 1.

Step 1: Determine the watershed characteristics of your entire site. For this example we have a 2.2 acre site with 1.4 acres of impervious area and 0.8 acres of pervious area in type B soils. The pervious area includes the turf area and the area of the biofiltration basin.


Screen shot of the MIDS calculator Schematic tab for the bioretention with elevated underdrain example. See Step 3.

Step 2: Fill in the site specific information into the *Site Information* tab. This includes entering a ZIP Code (55414 for this example) and the watershed information from Step 1. The Managed turf area includes the turf area and the area of the bioretention basin. ZIP code and impervious area must be filled in or an error message will be generated. Other fields on this screen are optional.

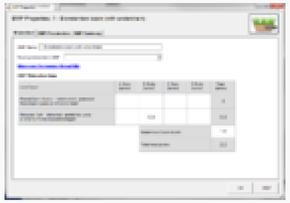
Step 3: Go to the Schematic tab and drag and drop the *Bioretention basin (with underdrain)* icon into the *Schematic* window.

Step 4: Open the BMP properties for the bioretention basin by right clicking on the *Bioretention basin (with underdrain)* icon and selecting *Edit BMP Properties*, or by double clicking on the *Bioretention basin (with underdrain)* icon.

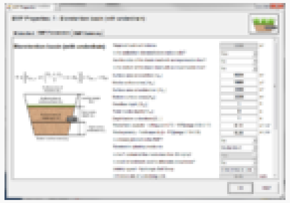
Step 5: If help is needed click on the *Minnesota Stormwater Manual Wiki* link or the *Help* button to review input parameter specifications and calculations specific to the *Bioretention basin (with underdrain)* BMP.

Step 6: Determine the watershed characteristics for the Bioretention basin. For this example the entire site is draining to the bioretention basin. The watershed parameters therefore include a 2.2 acre site with 1.4 acres of impervious area and 0.8 acres of pervious turf area in type B soils. There is no routing for this BMP. Fill in the BMP specific watershed information in the *Watershed* tab (1.4 acres on impervious cover and 0.8 acres of Managed turf in B soils).

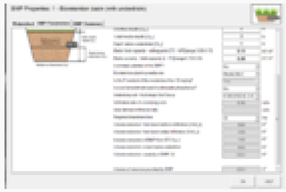
MIDS calculator screen shots for inputs for bioretention with an elevated underdrain. Click on an image for enlarged view.



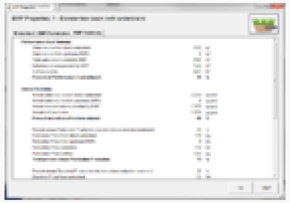
Screen shot showing Watershed tab for bioretention with an elevated underdrain. See Step 6.



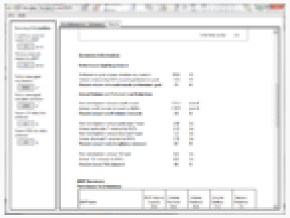
Screen shot showing BMP Parameters tab for bioretention with an elevated underdrain. See Step 7.



Screen shot showing BMP Parameters tab for bioretention with an elevated underdrain. See Step 7.



Screen shot of the BMP Summary tab for bioretention with an elevated underdrain. See Step 8.



Screen shot of Results tab for the example of a bioretention system with an elevated underdrain. See Step 10.

Step 7: Enter the BMP design parameters into the *BMP parameters* tab. This bioretention basin with an elevated underdrain example would require the following entries:

- Is the underdrain elevated above native soils – Yes;

- Are the sides of the basin lined with an impermeable liner – No;
- Is the bottom of the basin lined with an impermeable liner – No;
- Surface area at overflow [A_O]: 6534 square feet;
- Media surface area [A_M]: 5600 square feet;
- Surface area at underdrain [A_U]: 3948 square feet;
- Bottom surface area (area at media-soil interface) [A_B]: 3230 square feet;
- Overflow depth [D_O]: 1 foot;
- Total media depth [D_M]: 3 feet;
- Depth below underdrain [D_U]: 1 foot;
- Media field capacity minus wilting point [FP-WP]: 0.11 cubic feet per cubic foot;
- Media porosity minus field capacity [n-FC]: 0.26 cubic feet per cubic foot;
- Is a tree(s) planted in the BMP – No;
- Bioretention planting media mix – Media Mix C (selected in dropdown box);
- Is the P content of the media less than 30 mg/kg – autofills to “Yes” for Media Mix C;
- Is a soil amendment used to attenuate phosphorus – No;
- Underlying soil – Hydrologic Soil Group: SM (HSG B; 0.45 in/hr) (selected in dropdown box); and
- Required drawdown time: 48 hours (selected in dropdown box).

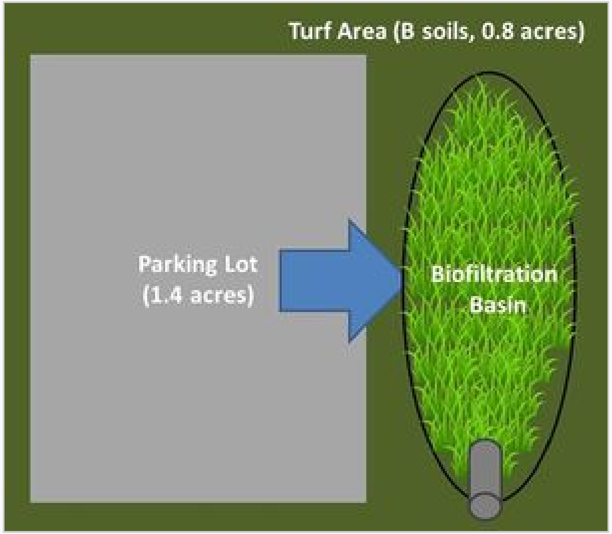
Step 8: Click on *BMP Summary* tab to view results for this BMP.

Step 9: Click on the *OK* button to exit the *BMP Properties* screen.

Step 10: Click on *Results* tab to see overall results for the site.

Biofiltration Basin with an underdrain at bottom example (Version 2)

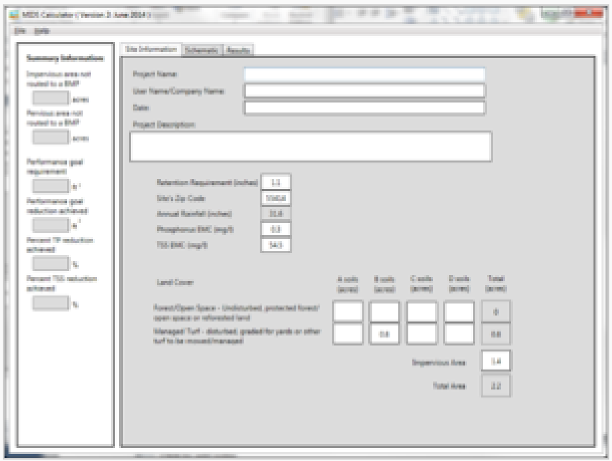
An unlined biofiltration basin with an underdrain at the bottom is to be constructed in a watershed that contains a 1.4 acre parking lot surrounded by 0.8 acres of pervious area (turf area and the bioretention BMP area). All of the runoff from the watershed will be treated by the biofiltration basin. The soils across the area have a unified soils classification of SM (HSG type B soil). The surface overflow is located 1 ft above the media surface. The surface area of the biofiltration basin at the overflow point will be 6534 square feet. The area is 5600 square feet at the media surface. The area at the media-soil interface is 3320 square feet. The total media depth will be 3 feet. The media will be Media Mix C, which is mostly sand resulting in a difference between the media wilting point and field capacity of 0.11 cubic feet per cubic foot and a difference between the media porosity and field capacity of 0.26 cubic feet per cubic foot. The P content of the media is less than 30 mg/kg (milligrams per kilogram) and no soil amendments will be used to



Schematic used for MIDS calculator example for bioretention with an underdrain at the bottom. In this example there is 1.4 acres of impervious parking draining to the bioretention basin. Pervious area is 0.8 acres and includes the turf area and the bioretention BMP. See Step 1.

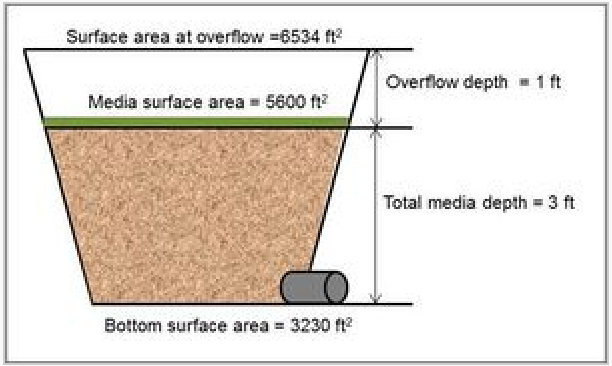
attenuate phosphorus. The following steps detail how this system would be set up in the MIDS calculator.

Step 1: Determine the watershed characteristics of your entire site. For this example we have a 2.2 acre site with 1.4 acres of impervious area and 0.8 acres of pervious area in type B soils. The pervious area includes the turf area and the area of the biofiltration basin.



Screen shot of the Site Information tab for the MIDS example for bioretention with an underdrain at the bottom. The user must input impervious acres and ZIP code. Other fields are optional. See Step 2.

Step 2: Fill in the site specific information into the *Site Information* tab. This includes entering a Zip Code (55414 for this example) and the watershed information from Step 1. The Managed turf area includes the turf area and the area of the bioretention basin. Zip code and impervious area must be filled in or an error message will be generated. Other fields on this screen are optional.



Step 3: Go to the *Schematic* tab and drag and drop the *Bioretention basin (with underdrain)* icon into the *Schematic* window.

Step 4: Open the BMP properties for the bioretention basin by right clicking on the "Bioretention basin (with underdrain)" icon and selecting *Edit BMP Properties*, or by double clicking on the *Bioretention basin (with underdrain)* icon.

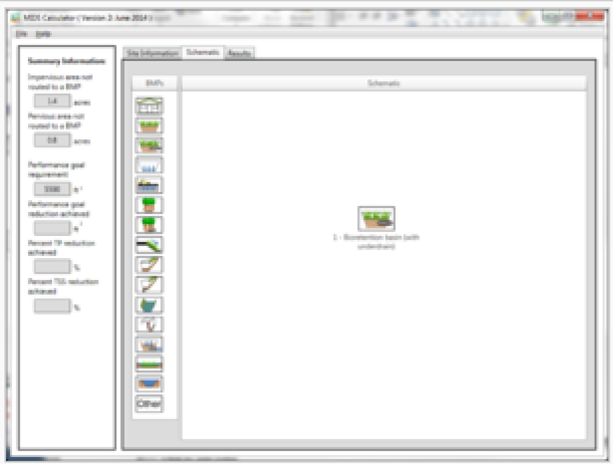
Step 5: If help is needed click on the *Minnesota Stormwater Manual Wiki* link or the *Help* button to review input parameter specifications and calculations

Schematic used for the MIDS calculator example for bioretention with an underdrain at the bottom. See Step 1.

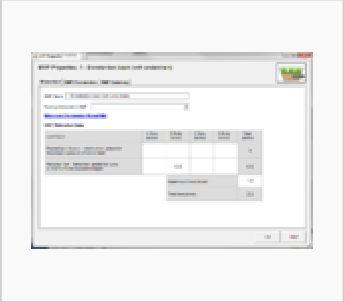
pertinent to the “Bioretention basin (with underdrain)” BMP.

Step 6: Determine the watershed characteristics for the biofiltration basin. For this example the entire site is draining to the biofiltration basin. The watershed parameters therefore include a 2.2 acre site with 1.4 acres of impervious area and 0.8 acres of pervious turf area in type B soils. There is no routing for this BMP. Fill in the BMP specific watershed information in the *Watershed* tab (1.4 acres on impervious cover and 0.8 acres of Managed turf in B soils).

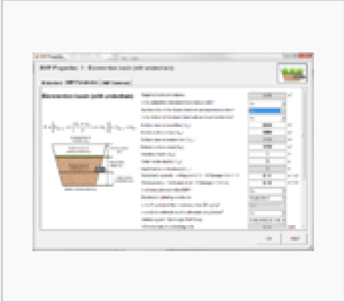
MIDS calculator screen shots for inputs for bioretention with an underdrain at the bottom. Click on an image for enlarged view.



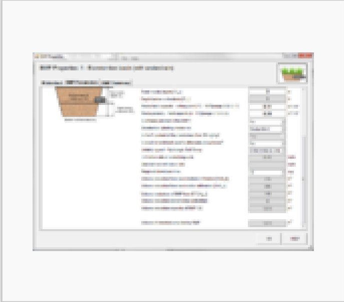
Screen shot of the Schematic tab for the MIDS calculator example for bioretention with an underdrain at the bottom. See Step 3.



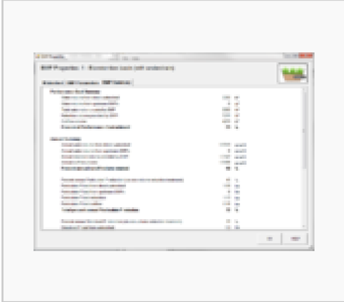
Screen showing Watershed tab for bioretention with an underdrain at the bottom. See Step 6.



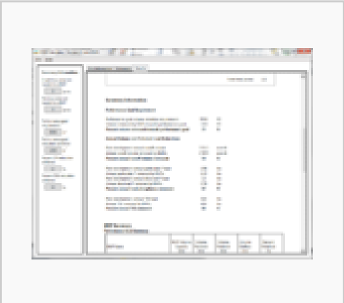
MIDS calculator screen shot showing BMP Parameters tab for bioretention with an underdrain at the bottom. See Step 7.



MIDS Calculator screen shot showing BMP Parameters tab for bioretention with an underdrain at the bottom. See Step 7.



MIDS Calculator screen shot of the BMP Summary tab for bioretention with an underdrain at the bottom. See Step 8.



Screen shot of the Results tab for the example of a bioretention system with an underdrain at the bottom. See Step 10.

Step 7: Enter in the BMP design parameters into the *BMP Parameters* tab. This bioretention basin example with an underdrain at the bottom of the media requires the following entries:

- Is the underdrain elevated above native soils – No;
- Are the sides of the basin lined with an impermeable liner – No;
- Is the bottom of the basin lined with an impermeable liner – No;

- Surface area of overflow [A_O]: 6534 square feet;
- Media surface area [A_M]: 5600 square feet;
- Bottom surface area (area at media-soil interface) [A_B]: 3230 square feet;
- Overflow depth [D_O]: 1 foot;
- Total media depth [D_M]: 3 feet;
- Media field capacity minus wilting point [FC-WP]: 0.11 cubic feet per cubic foot;
- Media porosity minus field capacity [n-FC]: 0.26 cubic feet per cubic foot;
- Is a tree(s) planted in the BMP – No;
- Bioretention planting media mix – Media Mix C (selected from the dropdown box);
- Is the P content of the media less than 30 mg/kg – autofills to "Yes" for Media Mix C;
- Is a soil amendment used to attenuate phosphorus– No;
- Underlying soil – Hydrologic Soil Group: SM (HSG B; 0.45 in/hr) (selected from the dropdown box); and
- Required drawdown time: 48 hrs (selected from the dropdown box).

Step 8: Click on *BMP Summary* tab to view results for this BMP.

Step 9: Click on the *OK* button to exit the *BMP properties* screen.

Step 10: Click on *Results* tab to see overall results for the site.

Requirements

Warning: The following are requirements of the Minnesota Construction Stormwater General Permit

- At least a 3 foot separation from the bottom of an infiltration system (includes bioretention with elevated underdrain) to the seasonal high water table
- If soils below the bottom of the infiltration system are ripped to promote infiltration, at least 2 feet of separation from the bottom of the ripped zone to the seasonal high water table
- Use the most restrictive infiltration rate within 5 feet of the bottom of the BMP
- For measured infiltration rates, apply a safety factor of 2
- Pretreatment for infiltration systems

Recommendations

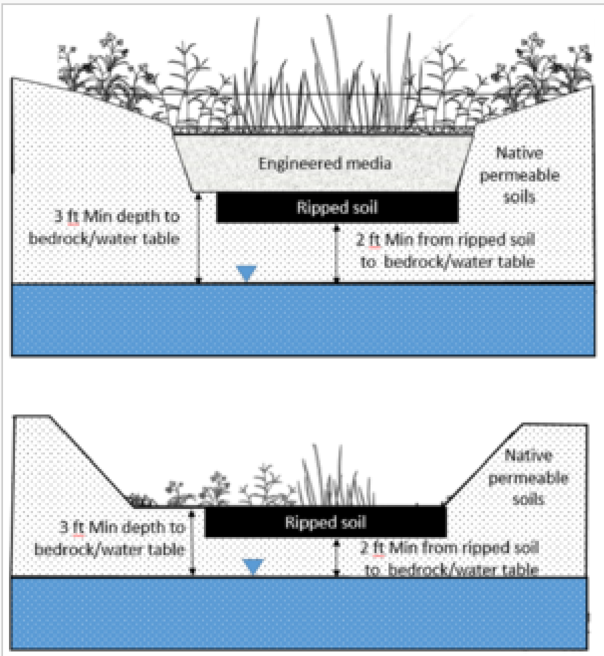
Caution: The following are recommendations for inputs into the MIDS Calculator

- Drawdown time of 24 hours when the discharge is to trout streams
- Use of field tested infiltration rates rather than table values

Information

Information: The following information may be useful in determining inputs for the MIDS Calculator

- Guidance on determining infiltration rates
- Information on site constraints (shallow soil, karst, etc.)
- Guidance on pretreatment
- Information on soil mixes
- Construction specifications for bioretention BMPs
- Information on operation and maintenance of bioretention BMPs.



Measurement of depth from the bottom of the infiltration BMP (bioretention with elevated underdrain) to the seasonally high water table or bedrock. Note that there must be a minimum of 2 feet separation when soils beneath the BMP are ripped, with a total separation distance of 3 feet or more. Infiltration BMPs include any BMP that allows water to infiltrate into the underlying soil.

Links to MIDS pages

- Overview of Minimal Impact Design Standards (MIDS)
- Performance goals for new development, re-development and linear projects
- Design Sequence Flowchart-Flexible treatment options
- Community Assistance Package
- MIDS calculator
- Performance curves for MIDS calculator
- Training and workshop materials and modules

- Technical documents

Categories: Table | References | MIDS calculator example | MIDS calculator guidance